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ON THE GENERAL THEORY OF CURVED SURFACES AND RECTILINEAR CONGRUENCES

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During the past two or three years, I have presented several communications to the American Mathematical Society concerning the general theory of curved surfaces and rectilinear congruences. I have been unable to find the leisure to write out in full my results, and take the present opportunity to gather together a few of the more important, in the hope that I may soon be in position to publish an extended treatment elsewhere.

Let the non-developable surface S be referred to a non-conjugate parametric net (u, v). Its equations in homogeneous coordinates may be taken in the form

$$y^{(k)} = y^{(k)}(u, v) \qquad (k = 1, 2, 3, 4), \tag{1}$$

where the determinant $|y_{uv}, y_u, y_v, y|$ is nowhere zero, and the four functions $y^{(k)}$ will then be a fundamental system of solutions of a completely integrable system of partial differential equations[1]

$$\begin{aligned} y_{uu} &= a\,y_{uv} + b\,y_u + c\,y_v + d\,y, \\ y_{vv} &= a'y_{uv} + b'y_u + c'y_v + d'y. \end{aligned} \tag{2}$$

The coefficients in these equations are functions of u, v which satisfy certain conditions of complete integrability, which we shall not write out here. Suffice it to say that if the integrability conditions are identically satisfied, any derivative of y is expressible, and in only one way, as a linear combination of y_{uv}, y_u, y_v, y,

$$\frac{\partial^{p+q} y}{\partial u^p\, \partial v^q} = a^{(pq)} y_{uv} + b^{(pq)} y_u + c^{(pq)} y_v + d^{(pq)} y. \tag{3}$$

The two points defined by the equations

$$\rho = y_u - \nu y, \qquad \sigma = y_v - \mu y, \tag{4}$$

where μ and ν are functions of u, v, lie on the tangents to the parametric curves. Let us denote by l the line joining ρ and σ; we have thus associated with each point y of the surface a definite line l lying in the corresponding tangent plane. The congruence of lines l we shall denote by Γ.

Again, if μ and ν are any functions of u, v, the point

$$z = y_{uv} - \mu y_u - \nu y_v \tag{5}$$

does not lie in the tangent plane to S at y, and the line l' joining y and z therefore protrudes from the surface. The lines l' constitute a congruence Γ'.

If, now, the functions μ and ν are the same in equations (4) and (5), the lines l and l' are in a certain characteristic geometric relation, which may be described as follows: The ruled surface $R^{(u)}$ formed by the tangents to the curves v = constant along a fixed curve u = constant is skew, since the parametric net is non-conjugate. This ruled surface is touched, in the point ρ defined by (4), by the plane determined by the line l' and the tangent $y\ y_u$. Similarly the point σ is the point in which the plane determined by l' and the other parametric tangent $y\ y_v$ is tangent to the ruled surface $R^{(v)}$ formed by the tangents to the curves u = constant along a fixed curve v = constant. The line l is therefore determined uniquely by the line l', and, conversely, if the line l is given, or in other words the points ρ and σ, the line l' is defined as the line of intersection of the tangent planes to the ruled surfaces $R^{(u)}$ and $R^{(v)}$ constructed at the points ρ and σ. The relation between the lines l and l', or between the congruences Γ and Γ', is a reciprocal one, which for want of a better name I shall call the *relation* R. It is determined of course by the particular parametric net to which the surface is referred.

The developables of the congruence Γ' cut the surface S in a net of curves whose differential equation is

$$\begin{aligned}&\left[c^{(21)} - c\mu - \nu_u + \nu\,(a^{(21)} - a\mu - \nu)\right]du^2\\ &+\left\{c^{(12)} - c'\nu - \nu_v + \nu\,(a^{(12)} - a'\nu - \mu) - \left[b^{(21)} - b\mu - \mu_u + \mu\,(a^{(21)} - a\mu - \nu)\right]\right\}dudv\\ &-\left[b^{(12)} - b'\nu - \mu_v + \mu\,(a^{(12)} - a'\nu - \mu)\right]dv^2 = 0.\end{aligned} \tag{6}$$

The quantities with double upper indices are coefficients of equations of the form (3). Likewise, the developables of the congruence Γ correspond to a net of curves on S defined by the differential equation

$$[d-\nu_u+(b-\nu)\nu+c\mu+a(\mu_u+\mu\nu)]\,du^2$$
$$+\{a'[d-\nu_u+(b-\nu)\nu+c\mu]-a[d'-\mu_v+b'\nu+\mu(c'-\mu)]+\mu_u-\nu_v\}\,dudv \quad (7)$$
$$-[d'-\mu_v+b'\nu+\mu(c'-\mu)+a'(\nu_v+\mu\nu)]\,dv^2=0.$$

The consideration of these developables, together with the focal points of the lines l and l', leads to many theorems which are generalizations of known theorems concerning conjugate nets. The point-conjugate of the surface S with respect to Γ', i.e., the surface generated by the harmonic conjugate of y with respect to the focal points of l', plays an important part in the discussion.

Of more immediate interest is the case in which the parametric net consists of the asymptotic curves of S. The differential equations of the surface may then be written[2]

$$y_{uu}+2by_v+fy=0,\quad y_{vv}+2a'y_u+gy=0, \quad (8)$$

and the differential equations defining the developables of the congruences Γ' and Γ respectively

$$[f+\nu^2+\nu_u-2b\mu+2b_v]\,du^2+(\nu_v-\mu_u)\,dudv$$
$$-[g+\mu^2+\mu_v-2a'\nu+2a'_u]\,dv^2=0, \quad (9)$$

$$[f+\nu^2+\nu_u+2b\mu]\,du^2+(\nu_v-\mu_u)\,dudv$$
$$-[g+\mu^2+\mu_v+2a'\nu]\,dv^2=0. \quad (10)$$

Especially interesting in this connection are the directrix congruences defined by Wilczynski.[3] These are in the relation R, since the directrix of the first kind is the line joining the points

$$r=y_u-\frac{a'_u}{2a'}y,\qquad s=y_v-\frac{b_v}{2b}y, \quad (11)$$

and the directrix of the second kind is the line joining the point y with the point

$$t=y_{uv}-\frac{b_v}{2b}y_v-\frac{a'_u}{2a'}y_v. \quad (12)$$

The following new geometric characterization of the directrix congruences may be given: *two congruences* Γ *and* Γ' *which are in the relation* R *to the asymptotics of a surface* S, *are the directrix congruences of* S *if and only if their developables correspond to the same net on* S.

A number of propositions, which Wilczynski has proved for the directrix congruences, subsist also for any congruences Γ and Γ' in the relation R with respect to the asymptotic net of the surface.

In the general case, i.e., when the parametric net is not necessarily asymptotic, the developables of the congruence Γ correspond to a conjugate net on S if and only if $\mu_u - \nu_v = 0$. Borrowing a locution of Guichard's, used by him in a quite different connection, I shall say that a congruence Γ is *harmonic to a surface S* if its developables correspond to a conjugate net on S. *If a congruence Γ is harmonic to a surface S, or if its developables correspond to the asymptotic curves of S, and then a line l of Γ is met in its focal points by the tangents to the curves corresponding to the developables of Γ, and conversely.* This theorem is a generalization of a corresponding theorem for the case in which the parametric net is conjugate and the congruence Γ is the *ray congruence*, i.e., the congruence of lines joining the first and minus first Laplace transforms of the parametric conjugate net. The theorem affords a new geometric characterization of conjugate nets with equal Laplace-Darboux invariants.[4]

A geometric characterization of isothermal nets may be given in terms of the relation R. Let the surface be referred to an orthogonal net, and let the congruence Γ' consist of the normals to the surface. Then the parametric net is isothermal if and only if the developables of the related congruence Γ correspond to a conjugate net on S. This characterization, together with another, is soon to appear in the Transactions of the American Mathematical Society.

In what follows, I shall always suppose that the asymptotic net is parametric. Again borrowing a terminology used in a different sense by Guichard, I shall say that a congruence Γ' is *conjugate to a surface S* if its developables cut the surface in a conjugate net. Then *if the congruence Γ' is conjugate to the surface S, the related congruence Γ is harmonic to S, and conversely.* The two conjugate nets can coincide only when Γ and Γ' are the directrix congruences.

An important question naturally arises concerning the existence of congruences conjugate to a given surface and uniquely determined thereby. The surface normals form such a congruence, so that a projective generalization of metric theorems would demand the existence of a congruence projectively determined by the surface and conjugate to it. I have found that such a congruence is generated by the lines l' joining the point y with the point

$$\zeta = y_{uv} + \tfrac{1}{2}\left(\frac{a'_v}{a'} + \frac{b_v}{b}\right) y_u + \tfrac{1}{2}\left(\frac{a'_u}{a'} + \frac{b_u}{b}\right) y_v. \qquad (13)$$

The corresponding line l joins the points

$$\rho = y_u + \tfrac{1}{2}\left(\frac{a'_u}{a'} + \frac{b_u}{b}\right)y, \quad \sigma = y_v + \tfrac{1}{2}\left(\frac{a'_v}{a'} + \frac{b_v}{b}\right)y. \tag{14}$$

The following geometric characterization of these points ρ and σ will of course afford a characterization of the line $y\zeta$.

Let l be any line in the tangent line, and l' the corresponding line through the point y. Project the asymptotic curves on the tangent plane, from any point on l', and let C_1 and C_2 be the conics which osculate these projections at y. There exists but one pair of lines l, l' such that the interesections of l with the asymptotic tangents are the double points of the involution determined by the two pairs of points in which l cuts the conics C_1 and C_2. Let R and S be these double points; they are given by the expressions

$$R = y_u + \tfrac{1}{4}\frac{b_u}{b}y, \quad S = y_v + \tfrac{1}{4}\frac{a'_v}{a'}y. \tag{15}$$

Recalling that the directrix of the first kind intersects the asymptotic tangents in the points r and s defined by equations (11), one finds that the point ρ is the harmonic conjugate of r with respect to y and R, and σ is the harmonic conjugate of s with respect to y and S. This completes the required characterization.

The points R and S, whose coordinates are given by equations (15), are of importance for still another reason. Darboux has shown[5] that in terms of the non-homogeneous coordinates of a regular point of a surface the equation of the surface may be written in essentially either of the following two forms, provided a local tetrahedron of reference be properly chosen:

$$z = xy + \tfrac{1}{6}(x^3 + y^3) + \tfrac{1}{24}(Ix^4 + Jy^4) + \ldots,$$
$$z = xy + \tfrac{1}{6}(x^3 + y^3) + \tfrac{1}{24}xy\,(I^1x^2 + J^1y^2) + \ldots.$$

Darboux did not characterize either tetrahedron. The tetrahedron which gives rise to the first expansion was completely characterized by Wilczynski.[3] To obtain the second expansion, three of the vertices of the tetrahedron of reference must be taken at the points y, R, S, and the fourth at the intersection of the canonical quadric with the line corresponding to RS in the relation R.

The congruence of lines $y\zeta$, since its developables cut the surface in a conjugate net, would very naturally take the place of the congruence of normals to a surface in projective generalizations of metric theorems. The said conjugate net would then play the part of the lines of curva-

ture. If this conjugate net has equal Laplace-Darboux invariants, a particular class of surfaces analogous to isothermic surfaces is defined. A projective generalization of geodesics may be made in terms of the congruence $y\zeta$, since[6] there exists a two-parameter family of curves on the surface whose osculating planes contain the lines $y\zeta$. It must be possible also to generalize a good part of the theory of triply orthogonal systems and families of Lamé, although the generalization can never be complete on account of the essential differences between metric and projective space. The field seems, on the whole, to be very promising.

[1] Green, G. M., *Trans. Amer. Math. Soc., New York*, **17**, 1916, (483–516).
[2] Wilczynski, E. J., *Ibid.*, **8**, 1907, (233–260).
[3] Idem, *Ibid.*, **9**, 1908, (79–120).
[4] Green, G. M., *Amer. J. Math., Baltimore*, **38**, 1916, (313).
[5] Darboux, *Bull. Sci. Math., Paris*, (Ser. 2), **4**, 1880, (348–384).
[6] Cf. the abstract of Miss P. Sperry, *Bull. Amer. Math. Soc., New York*, **22**, 1915–1916, (441–442). The normal congruence is there replaced by the directrix congruence of the second kind, whose developables, however, do not cut the surface in a conjugate net.

A CONTRIBUTION TO THE PETROGRAPHY OF SOUTHERN CELEBES

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In a paper in the *Journal of Geology*, Chicago, **23**, 1915, (231–245), the authors described some rocks collected in Java and Celebes in 1910. The chemical analyses of seven of these were from lavas and coarsely crystalline igneous rocks occurring in the neighborhood of Bulu Saraung (Pic de Maros). The rocks analyzed are trachytes, absarokite, nephelite-syenite and fergusite, besides kentallenite and marosite, rocks related to shonkinite.

In November, 1914, a more extended visit was made to Southern Celebes under the auspices of the Bureau of Mines of the Netherlands Government. The mountainous region from Maros to Malawa and Batuku was studied in company with Mr. 'T Hoen and Mr. Ziegler, geologists of the Bureau. The region visited consists of several nearly parallel ranges of volcanic mountains, whose lavas are underlaid by faulted and dislocated strata which are exposed in the valleys and along the base of the volcanic ridges.

The faulting and dislocation of the limestones and coal-bearing shales antedated the eruption of the igneous rocks, for the distorted strata are overlaid by volcanic breccias which form much less disturbed beds

in nearly horizontal positions in some parts of the region, but have dome-like positions in other places where great bodies of intruded lavas have lifted the sedimentary strata and overlying breccias, and have formed large laccolithic masses. The sedimentary strata are also traversed by intrusive sheets or sills of igneous rocks which occupy slightly different horizons in adjacent blocks of faulted sediments, showing that their intrusion was subsequent to the faulting and dislocation of the sedimentary strata. Dikes of igneous rocks occur more abundantly in some localities than in others, but are not very numerous.

The volcanic breccias, which are probably the oldest eruptions of the series in this region, vary somewhat in different localities and in different parts of one mountain ridge. For the most part they are basaltic in appearance with small phenocrysts of augite and olivine, and very few of feldspar. The more feldspathic varieties occur chiefly in the breccia mountains heading the valley north of Bulu Saraung, that is, the southwestern end of the region visited. These rocks are mostly trachy-andesites, with small phenocrysts of augite and calcic plagioclase, in a groundmass of more alkalic feldspar which is in part orthoclase. With these andisitic breccias are associated more basaltic varieties and smaller amounts of trachytic rocks, some of which contain leucite. While most of this breccia is without noticeable bedding, is chaotic, parts of it are distinctly bedded and contain well-worn pebbles of the same kinds of rock as those forming the chaotic breccia.

Farther north-east, in the vicinity of Malawa and Batuku, the breccia is almost wholly basaltic, with phenocrysts of augite and olivine; some varieties containing abundant small leucites, some being rich in large leucites. Leucitophyres constitute a great part of the volcanic breccias of the ridges visited, and are said to occur throughout a range of mountains at least 60 miles in length. Leucite-bearing rocks have been found in scattered localities from the Saleier Islands at the southern extremity of Celebes to the northern end, a distance of about 500 miles.

Large bodies of lava have broken through the volcanic breccias in places, and have formed masses of trachyte and phonolite. This is the case especially in the southwest. The summit of Bulu Saraung (Pic de Maros) is phonolite which is younger than the basaltic breccias and tuffs that form the ridge to the east. Other large bodies of massive lava form peaks north of the road nead Bua. Dikes of porphyritic trachyte, and of other kinds of rocks, cut the breccias and sedimentary strata beneath them. A large dike of trachyte cuts limestone in the valley of the Sangara (Gentungen) above Balotji. It is exposed in a wall 6 feet thick and 30 feet high. Intrusive sills occur in the stratified

rocks and at the base of the breccias, and have a wide range of composition. Great sheets of basalt form cliffs with limestone west of Maros near Patinuan. West of Birau, which is north of B. Saraung, there are sills of fine-grained syenite and leucitophyre. Leucitophyres form sills in the coal-bearing strata near Batuku. Laccolithic bodies of great size occur at the west base of B. Saraung, also in the valley east of Tjamba, and in the valley of Malawa. The rocks forming the laccoliths vary somewhat in composition and in grain. The largest are shonkinites, fergusite and essexite, which merge at their margins into fine-grained and aphanitic porphyries, with small porphyritic leucites. Other laccolithic bodies are medium to fine-grained rocks, some of which are more feldspathic than the shonkinites, and approach monzonites and syenites. There are phases of the laccolithic rocks very rich in biotite, augite and olivine, and others, occurring as veins in the principal rocks, that are syenites and nephelite-syenites. In contrast to these feldspathic rocks are highly mafic lavas, found as boulders in streams, which consist almost wholly of augite and olivine.

While some parts of the igneous rocks in this region are much decomposed, the great majority of the boulders in the streams, and of massive exposures in place, are extremely fresh, even the crystals of leucite and olivine, although the lavas were probably erupted in late Tertiary times. This may be due to the absence of frost and the vigorous surface action of abundant rains and strongly flooded streams.

A large collection of rocks from the localities visited shows the great variety of leucitic lavas and the freshness of the rocks in most instances. The accompanying chemical analyses of twelve specimens illustrate the most interesting varieties so far studied. In addition to the seven analyses previously published in the *Journal of Geology*, and those published and described by A. Schmidt, they furnish a fair idea of the chemical composition of the igneous rocks of this part of Celebes.

Analysis 1 is of a non-porphyritic trachytic phonolite, which forms the summit of Bulu Saraung (Pic de Maros). It is holocrystalline with a trachytoid texture, and consists of prismoid alkalic feldspar with abundant minute crystals of what is probably sodalite. There is a small amount of brownish green pyroxene, which is slightly pleochroic, colorless wallastonite, and euhedral magnetite. Analysis 2 is of a porphyritic pseudoleucite-trachyte, with large phenocrysts of altered leucite, now analcite, and fewer of orthoclase and plagioclase. Analysis 3 is of a porphypitic leucite-trachyte with phenocrysts of augite, biotite and altered leucite, in a groundmass of alkalic feldspar and biotite.

Analysis 4 is of a leucitophyre from Batuku. The phenocrysts of

leucite are large and fresh,—also of various sizes, to microscopic dimensions. The groundmass consists of small augites, prismoids of alkalic feldspar, magnetite and blades of ilmenite. Analysis 5 is of a minette, an aphanitic rock, with microscopic phenocrysts of biotite, magnetite, feldspar and augite, The groundmass consists of alkalic feldspar, biotite, augite and anhedral calcite, with some sodalite or altered leucite. The calcite is secondary.

The following six analyses are of shonkinites and leucitophyres. The shonkinites differ from one another, somewhat in composition, and might possibly be given different names. That from which analysis 6 was made is from the laccolith east of Tjamba. It resembles a medium-grained gabbro, and consists largely of augite, with less olivine and magnetite, a small amount of biotite, and considerable orthoclase, each crystal having a clouded core of altered plagioclase. There is also a zeolite, which probably replaces nephelite. The shonkinite, from which analysis, 7, was made, is much richer in biotite than the rock from East of Tjamba, is free from olivine, has abundant augite and orthoclase, besides clouded portions with a somewhat radiate structure, probably an intergrowth of feldspar and nephelite, now altered. There is also some zeolite as an alteration product. The shonkinite of analysis 8 is rich in augite and magnetite, with less feldspar, in part orthoclase, in part alkalic plagioclase, both with marginal intergrowths of a mineral with still lower refraction, which is probably altered nephelite. Analysis 10 is of another shonkinite with much augite. and orthoclase, and a zeolite which replaces pseudoleucite or nephelite.

The leucitophyre from Batuku, whose analysis is 9 has abundant phenocrysts of augite and fresh leucite, in a groundmass of small leucites and augites, with some plagioclase, magnetite, and secondary chlorite and zeolite. Analysis 11 is of a leucitophyre exceptionally rich in calcium oxide, and low in alumina. The rock has abundant phenocrysts of augite and fresh leucite, in a groundmass of small leucites, augite, anhedral wollastonite, and magnetite. The norm contains an unusually high percentage of wollastonite.

Analysis 12 is exceptional because of the low alumina and relatively high amount of potash. The rock from which it was made is an aphanitic porphyry, consisting mainly of augite with less olivine, as phenocrysts in a groundmass of augite, magnetite, and leucite. There is over 80% of mafic minerals, so that the rock is a leucitic limburgite, or a highly mafic leucitite. It is clearly an extremely mafic phase of leucitophyre, and since it does not correspond to any lava, so far described and analyzed, it seems advisable to name the rock batukite after the locality in which it occurs.

TABLE OF CHEMICAL ANALYSIS AND NORMS OF LAVAS FROM CELEBES

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2.....	58.33	56.59	50.72	49.42	47.00	48.06	46.27	46.32	46.45	46.45	45.70	47.72
Al_2O_3....	20.37	20.15	17.44	18.04	16.65	12.86	15.10	12.27	13.01	14.81	7.58	4.65
Fe_2O_3....	1.48	1.97	2.96	2.85	3.37	6.05	4.30	6.62	5.67	5.73	5.72	4.84
FeO.....	0.75	1.31	3.68	4.24	4.25	4.50	4.57	5.07	5.21	4.47	4.23	3.97
MgO....	0.30	1.09	2.98	3.16	2.58	3.26	6.70	6.34	6.44	4.97	4.76	16.98
CaO.....	2.81	3.81	5.18	6.66	6.28	12.72	8.27	12.45	11.74	9.55	21.66	15.43
Na_2O....	7.14	5.78	3.22	1.52	3.70	2.22	2.60	2.51	1.75	4.31	1.01	0.88
K_2O.....	6.17	4.63	7.74	9.24	6.90	4.71	5.04	3.49	4.82	4.25	3.79	2.27
H_2O+...	1.37	2.32	2.13	1.08	2.47	2.82	2.26	1.34	1.68	1.59	2.41	1.54
H_2O-...	0.18	0.85	0.39	1.07	0.44	0.48	0.53	0.28	0.43	0.54	0.99	0.43
TiO_2....	0.27	0.52	1.14	0.58	1.21	0.91	1.64	1.23	1.22	1.01	0.83	0.46
ZrO_2....	0.00	0.00	0.00	0.00	0.00	0.01	tr	0.02	0.01	0.00	tr	0.00
CO_2.....	0.10	0.00	0.24	0.03	3.59	0.01	0.53	0.01	0.22	0.00	0.18	0.00
P_2O_5.....	0.11	0.11	1.14	0.92	0.82	0.69	1.03	1.18	0.67	0.92	0.65	0.41
Cl.....	0.13	0.14	0.13	0.09	0.05	0.02	0.09	0.08	0.06	0.06	0.05	0.08
F.....	0.05	0.05	0.08	0.07	0.06	0.05	0.06	0.09	0.05	0.06	0.03	0.06
S.....	0.07	0.05	0.08	0.09	0.08	0.03	0.12	0.04	0.06	0.13	0.03	0.07
Cr_2O_3...	0.00	0.02	0.02	0.00	0.01	0.01	0.00	0.03	0.02	0.01	0.05	0.11
MnO....	0.38	0.37	0.37	0.27	0.60	0.29	0.55	0.55	0.33	0.54	0.33	0.15
BaO.....	0.05	0.02	0.20	0.38	0.14	0.24	0.19	0.21	0.17+	0.71 (2)	0.04	0.16
SrO.....	0.00	0.02	0.07	0.07	0.07	0.02	0.09	0.19	0.12	0.12	0.15	0.04
	100.07	99.80	99.93	99.58	100.29	99.96	99.94	100.32	100.13	100.23	100.19	100.25

NORMS

or.....	36.70	27.24	45.59	40.59	40.59	27.80	29.47	20.57	28.36	26.13	11.68	11.68
ab.....	35.11	42.44	10.48		3.14	10.48	7.34	7.86				
an.....	5.28	15.29	10.29	15.01	8.34	11.40	14.73	12.23	13.34	8.34	5.28	1.95
ne.....	13.63	3.41	9.09	6.82	15.34	4.26	7.95	7.10	7.95	13.06	4.54	4.26
lc.....				10.90						9.59	8.28	1.31
di.....	2.72	2.19	6.48	10.88	14.28	22.18	16.06	33.87	32.42	26.68	30.17	56.54
wo.....	1.86					8.12					24.94	
ol.....		1.56	5.58	5.44	2.56		8.91	1.99	2.96	1.70		13.31
mt.....	2.09	3.02	4.18	4.18	4.87	8.82	6.26	9.51	8.35	8.35	8.35	7.19
il.....	0.64	0.91	2.13	1.22	2.28	1.67	3.04	2.28	2.28	1.98	1.52	0.91
ap.....	0.34	0.34	2.69	2.02	2.02	1.68	2.35	2.69	1.68	2.02	1.68	1.01
etc.....	1.95	3.47	3.14	2.50	6.77	3.45	3.59	1.89	2.53	2.39	3.78	2.22
	100.32	99.87	99.65	99.56	100.19	99.86	99.70	99.99	99.87	100.24	100.22	100.38

1 Trachytic phonolite: beemerose-miaskose. I'. (5) 6. 1(2). (3) 4. Summit, Bulu Saraung. E. W. Morley.

2 Pseudo-leucite-trachyte: pulascose-laurvikose. I'. 5. 2. (3)4. East of Malawa. E. W. Morley

3 Pseudo-leucite-trachyte: ciminose-monzonose. II. 5(6). 2. (2)3. Stream S. W. of Bulu Saraung. E. W. Morley.

4 Leucitophyre: vicose. II. 6. 2. 2. Batuku. E. W. Morley.

5 Minette: borolanose. II. 6. '2. 3. Dike, stream S. W., of Bulu Saraung. E. W. Morley.

6 Skonkinite: lamarose. III. 5'. 2'. 3'. Laccolith east of Tjamba. E. W. Morley.

7 Shonkinite: ourose-shonkinose. (II)III. (5)6. 2(3). 3. Laccolith, road S. of Bulu Saraung. E. W. Morley.
8 Shonkinite: ourose-shonkinose. III. (5)6. 2(3). 3. Stream, Malawa. E. W. Morley.
9 Leucitophyre: ourose-ottajanose. III. '6. (2)3. 2(3). Stream, Batuku. E. W. Morley.
10 Shonkinite: kamerunose-cascadose. 'III. (6)7. 2. 3(4). Laccolith E. of Malawa. E. W. Morley.
11 Leucitophyre: ———. IV. '2. $_1$. 1. '$_4$. 2(3). Stream, Malawa. E. W. Morley.
12 Batukite, leucite-limburgite, brunose-belcherose. IV. 1(2). $_2$. 1. $_{2\cdot(3)}$. 1(2). Batuku. E. W. Morley.

ON THE NON-EXISTENCE OF NERVOUS SHELL-SHOCK IN FISHES AND MARINE INVERTEBRATES

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Experiments made at Tortugas, Florida, during the summer of 1917 indicate that the nervous systems of fishes and invertebrates are remarkably resistant to the injurious effects of sudden explosive shocks transmitted through the water.

Many experiments were made upon the Scyphomedusa *Cassiopea xamachana*. The medusae were paralyzed by removing their marginal sense organs, and then a ring-shaped strip of subumbrella tissue was set into pulsation by an induction shock; thus producing a single neurogenic contraction which travels through the circuit-shaped strip of tissue at a uniform rate of speed, provided temperature, salinity and other factors remain unchanged. It is thus possible accurately to ascertain not only the rate of nerve conduction but also the peculiar individual characteristics of the wave in each pulsating ring.

These rings were placed in a light silken bag immersed about 10 feet below the surface of the sea; and then a half stick of dynamite was exploded within 3 feet of them. This, however, produced no effect either upon their rates or the character of their pulsation waves, although fishes possessing swim-bladders were killed within 10 feet, and injured so that they turned ventral side uppermost within 20 feet of the exploding dynamite.

When the pulsating rings were placed in glass jars or tin cans, partially filled with air, the containers were crushed or shattered by the explosion and much mechanical injury sustained by the medusa rings, which however, could at once be restored to normal pulsation by an induction shock, if their pulsations had ceased. It was also observed that the lacerated area regenerated at a normal rate.

Prof. J. F. McClendon suggested that fishes with swim-bladders might

prove to be more sensitive to explosive shocks than those without swim-bladders, and experiments showed that a half stick of dynamite may be exploded within 3 feet of a small shark, which has no swim-bladder, without producing any apparent injury. This also applies to a lesser degree to such teleosts as lack swim-bladders. Dr. S. C. Ball kindly dissected some of the fishes with swim-bladders which had been killed by the explosions, and found that the swim-bladder had burst, and the tissues were crushed in around it, often breaking the vertebral column of the fish. Moreover, Prof. W. H. Longley, who has had much experience in the use of dynamite, tells me that echinoderms, and crustacea, if not mechanically torn apart, show no apparent ill effects but however move away from the site of the explosion.

It appears, then, that the nervous system of these lower forms is extraordinarily insensitive to shock due to explosion of dynamite, and that the injurious effects of the explosion if present are due to mechanical lacerations of tissues and especially the crushing inward of air-filled cavities. It seems possible, therefore, that the cavities of the middle ear and eustachean tubes may be a source of danger to men standing near exploding shells.

It has been suggested that the sudden reduction in atmospheric pressure in the close proximity of an exploding shell might set free dissolved gases in the blood and elsewhere, thus vacuolating the tissues and producing pressure and other effects upon the nerves; but our experiments with pulsating rings of *Cassiopea* seem to negative this hypothesis for no injurious effects other than those of simple asphyxiation were produced by sudden exhaustion of the air surrounding the animals; and recovery, when replaced in normal sea water, was almost immediate.

These results are in accord with the conclusion of Grasset, Eder, Babinski et Froment, and others that war shock is predominantly a psychic phenomenon, and being hysteria it can be cured by hypnotic suggestion.

CHEMICAL DIFFERENTIATION OF THE CENTRAL NERVOUS SYSTEM IN INVERTEBRATES

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The selective action of drugs for certain tissues forms the basis of the science of pharmacology. The action of such substances as strych-

nine in increasing the sensitivity of the sensory-motor junctions of the spinal cord is definitely known. In a more general way the selective affinity of caffein, camphor and atropin for specific parts of the vertebrate central nervous system has been established.

As an instance of the application of this method to the study of the nervous systems of other forms, Baglioni[1] has attempted an analysis of the cephalopod ganglia by means of strychnine and phenol. Strychnine was found to be specific for the cerebral ganglia and phenol for the mantle ganglia.

The writer recently has found that freshly hatched squid (Loligo pealii) furnish excellent material for demonstrating reactions of the type under discussion. These little animals show a delicate sensitivity to the action of the substance used. Their response to stimulation is easily demonstrable in the muscular convulsions of tentacles, neck and mantle, and the spasms are in every case, except where specifically inhibited, accompanied by a striking play of the chromatophores. The cephalopod chromatophore is a globular sac containing either yellow, red or brown pigment. At rest these bodies appear as small dark spots, scattered inconspicuously over the surface of the mantle, head and tentacles. Muscle fibers attached radially to the chromatophore control its form. Contraction of these fibers stretches the sac into a sheet, so that the surface of a given chromatophore may be increased a hundred-fold by this mechanism.

The result of strong stimulation, such as mechanical injury or the action of potassium chloride, is a series of clonic spasms of the entire musculature, invariably involving extreme extension of the chromatophores. The play of brilliant color may therefore be used as an indicator of stimulation. If the precaution is taken to view the animals against a white background, the reaction can be followed with the naked eye. Details can be studied with the aid of the low power objective of the microscope.

In carrying out an experiment, a half dozen freshly hatched squid were put into a Syracuse watch glass containing a solution of the substance to be tested. In sufficiently dilute solutions the characteristic effects could be followed for an hour or longer. A strychnine sulfate solution (1: 100,000) maintained the squid in a highly sensitive state for over an hour, so that a slight jar was sufficient to throw the animal into spasms and bring on the play of chromatophores over the entire body.

When put into caffein solution (1: 10,000) juvenile squid show rapid circus movements. The circular character of the course is due to the

cramped bending of the neck. The tentacles also show convulsions. At the same time a lively expansion of the chromatophores takes place in the entire head region and solely in this region. Only rarely may the display extend to the mantle.

In sea water one-sixth saturated with camphor gum, the reaction of young squid is exactly the reverse of that in caffein. While the head and tentacles remain passive and their chromatophores closed, the muscular spasms and the play of color take place in the mantle. The fact that the camphor acts directly on the mantle (stellar) ganglia may be demonstrated in the following way. With the stroke of a sharp scalpel sever the head from the body of the squid. In a few seconds the results of mechanical stimulation have abated and both parts are at rest with the chromatophores closed. Now put the two parts of the animal, head and body, into the camphorated sea water. The mantellar region shows muscular convulsions and the brilliant play of chromatophores, while the head and tentacles remain quiescent unless stimulated directly.

Juvenile squid immersed in atropin sulfate solution (1:2500) show abnormally rapid swimming movements, soon followed by failure of locomotion. The animals lie on the bottom of the dish and with the microscope one may see the spasmodic contractions of the tentacles and mantle. There is no play of the chromatophores. This fact distinguishes atropin spasms from those due to strychnine, caffein and camphor. It may be that the failure of the radial muscles of the chromatophores to contract is due to the blocking of the impulses to these muscles. In such a case we would have an analogy in the action of atropin in paralyzing the terminations of the sympathetic in vertebrates.

Crustaceans are far less favorable material for the study of the selective action of drugs. This is undoubtedly in part due to a failure of the substance used to penetrate the tissues. The writer has shown that certain fresh water crustaceans are rendered more sensitive to light by treatment with solutions of strychnine, atropin and caffein.[2] Striking results may also be obtained in marine forms with saturated solutions of camphor gum. Specimens of the hermit crab (Pagurus longicarpus) after a few minutes' immersion in the solution of camphor gum in sea water are seized with tremors at each attempt at locomotion. This is due to the fact that all the appendages are thrown into convulsive trembling movements resembling the symptoms of palsy in human beings. Similar effects may be observed in the marine shrimp (Crangon vulgaris). In this form the thoracic appendages first show tremors, then complete paralysis. The swimmerets are next extended at right angles

to the median line of the body and show continuous tremors. At this stage, the animal, when stimulated, invariably swims forward, and is entirely unable to move backward. This is due to the fact that the swimmerets are able to make only the stroke which carries the animal forward. This fact may indicate that camphor acts selectively on the ganglia of the abdominal nerve cord, paralyzing the motor elements which control backward swimming, and rendering more sensitive the nervous elements controlling forward movement. Eventually complete paralysis supervenes.

Further tests were made to determine the character of the action of strychnine, atropin, caffein and camphor on starfish (Asterias), medusa (Gonionemus) and the sea anemone (Metridium). In the case of medusa and sea anemone, atropin alone was an effective reagent in increasing the animal's sensitivity. A sea anemone put into atropin sulfate solution (1: 2000) upon stimulation withdraws the tentacles, contracts the sphincter, and spasmodically contracts the longitudinal muscles. The animal does not fully recover the relaxed condition in the atropin solution but revives in a few minutes in a stream of fresh sea water. Specimens of medusa put into atropin sulfate solution (1: 2500) contract their tentacles and show continuous activity of the bell with an abnormally high rate of pulsation. Starfish were affected by atropin in the same way as by strychnine, viz: the animals show a strong tendency to bend the rays dorsalward, which is increased by stimulation. Caffein and camphor are not effective in increasing the irritability of starfish.

These results indicate an increased chemical complexity of the central nervous system developing *pari passu* with an increase in morphological complexity. Thus, in the actinian and coelenterate where the diffuse nerve net system obtains, strychnine, caffein and camphor exert no excitatory action. With the development of localized nerve tracts and the beginning of a central nervous system in the asteroids, strychnine, in comparatively high concentrations, produces its characteristic effects. In crustacea and the cephalopod mollusca with their highly developed central nervous systems, the strychnine is, as we should expect, effective in low concentrations. Caffein and camphor act as excitants only where the histological elements of the nervous system are completely elaborated, viz.: in crustacea and the cephalopod mullusca.

Atropine stands in a separate category, since it is effective as a nerve excitant in members of all the classes tested. It would seem, then, that atropine forms a compound with a fundamental constituent of all the nerve cells, while strychnine, caffein and camphor combine with neuronic molecules which are the products of a higher organization.

Summary.—As evidence for the chemical differentiation of the central nervous system in invertebrates, it has been shown that, in the cephalopod (Loligo pealii), caffein brings about hyperirritability of the cerebral ganglia, while camphor affects the stellar ganglia alone in the same sense. Atropin causes spasms in the squid, but inhibits the activity of the chromatophores.

Camphor shows a selective action on the central nervous system of the shrimp (Crangon vulgaris) paralyzing the elements which function in backward swimming movements and exciting those controlling forward movement.

Atropin increased the sensitivity of all the forms tested.

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[2] Moore, A. R., *Science, New York*, N. S., **38**, 1913, (131–133).

PROOF OF THE MUSCLE TENSION THEORY OF HELIOTROPISM

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That the mechanism by which heliotropic organisms are oriented to light should be identical with that for the orientation to the galvanic current was demanded by the tropism theory developed by Loeb in 1888.[1] The identity of the mechanism in sessile forms was early established by Loeb, while more recently Bancroft[2] has clearly shown that the tenets of the theory hold also in the movements of *Euglena*, which are accomplished in an identical way whether under the influence of light or of the constant current.

It is the aim of this paper to show that the movements of many heliotropic insects under the influence of light are to be explained as forced motions due to the effects of light upon the tension or tonus of the muscles and that in this regard, there exists an exact analogy to the effects of the constant current in the animals investigated.

Loeb and Maxwell[3] showed that when a constant current passed from side to side of *Palæmonetes* the legs on the anodal side were flexed, while those on the cathodal side were extended. With the anode at the anterior end the anterior legs were flexed and the posterior extended. Reversal of the current reversed the condition of tension in these legs and body changes were also induced. The whole response persisted while the current flowed and put the animals in such a condition that any movement forced them toward the anode. Similarly it was shown

by Loeb and Garrey[4] that *Amblystoma* larvae reacted to the constant current in such a way that the muscle tonus was different depending upon the direction of the current. With the anode at the anterior end, the body curved ventrally and the legs were directed backward, while with the cathode at the head end the body was in the opisthotonic condition, concave dorsally, and the legs were directed forward. These differences in muscle tension made motion difficult or impossible in any direction except to the anode, toward which the animals were forced to move.

In the heliotropic insects the characteristic reactions are mediated through the eyes, the central nervous system, and thus reflexly, the musculature. Loeb proposed the following theory of the direction of the motions of such heliotropic animals.[5] The "photosensitive elements are arranged symmetrically in the body and through nerves are connected with symmetrical groups of muscles. Light causes chemical changes in the eyes. . . . . If the rate of photochemical reaction is equal in both eyes the effect upon symmetrical muscles is equal, and the muscles of both sides of the body work with equal energy. If a positively heliotropic animal is struck by light from one side, the effect on the tension or energy production of muscles connected with this eye will be such that an automatic turning of the head and the whole animal toward the source of light takes place," until the eyes are equally illuminated, when the symmetrical muscles work equally so that the animal will continue to move in this direction, or any deviation from this line of orientation will result in a repetition of the manouver.

It is our purpose to show that inequality in the illumination of the two eyes of many insects does in reality produce the differences in muscular tension demanded by this theory, that their movements are determined by this condition, that the phenomena are quite general in this group of animals and identical with those described for galvanotropism where the tension theory is proven.

Holmes[6] showed that the tonus of the muscles of the water scorpion, *Ranatra*, was markedly affected by illuminating the animal from different directions and by blackening different parts of the eyes, thus changing the equality and symmetry of illumination of the two sides. His results were in absolute harmony with Loeb's theory, the animals reacted according to its demands with 'machine-like' precision. The striking similarity to the behavior of *Palæmonetes* or *Amblystoma* when under the influence of the galvanic current would have sufficed to establish the identity of heliotropism with galvanotropism, had it not been for the diverting effect of Holmes's psychological speculation,

centering as it did upon other features in the behavior of *Ranatra*. This case stands as an isolated example whereas, the features it presents are in reality generally applicable to heliotropic animals, since our experiments have demonstrated their existence in practically every group of the insecta. They are well shown by many genera of butterflies and moths, by the bees, by many of the commoner flies including *Musca*, *Caliphora*, *Tabanus*, and *Eristalis*. While future reference will be made to these forms, the present communication will deal mainly with the reactions of the robber flies, in some forms of which the effects of light on the muscle tonus are most striking. The best of these which has come to our notice is one of the large brown forms, *Proctacanthus*, although *Promachus* and *Deromyia* show the reactions well.

Methods were used to produce unequal illumination, usually by blackening some part of the eyes with asphalt black, which is practically opaque and hardens into a brittle shell-like film upon drying.

1. Blackening all of one eye. When one eye of positively heliotropic insects is blackened, circus motions are made toward the opposite (normal) side and in all the forms studied they occur both when flying and creeping, as noted by Parker for *Vanessa antiopa*.[7] They may be noted in practically all of the commoner butterflies. Differences in the tonus of the muscles of the two sides are in evidence when the animals are at rest under constant illumination. The bodies are tilted well toward the side of the good eye and the legs of that side are flexed with the body resting against their upper segments, while the terminal segments of that side are well under the body, and those of the opposite side are extended away from the body. The head is usually rotated on the body so that both antennae may actually be below the line of the wings.

The robber fly, *Proctacanthus* (Sp. ?) shows the tonus changes of the legs much more strikingly than any other insect examined. On the side of the good eye they show a continued state of flexion involving all three legs. The anterior leg may be so far adducted as to cross under the body farther to the side of the blackened eye than the corresponding leg of that side. The legs on the side of the blackened eye are more extended than normally and spread farther apart. The body may tilt so far toward the side of the normal eye as to press the legs to the table. The head not only rotates on the long axis of the body toward the good eye but is also flexed toward that side, a considerable angle appearing between the head and thorax. In some cases the abdomen also shows flexion concavely toward the side of the good eye even when the animal is at rest. The posture assumed is the characteristic one assumed by

Palæmonetes when the constant current is passed through the body from side to side, and by *Ranatra* when illuminated from one side. The figures of the authors referred to above in this connection will serve for illustration of the conditions resulting from our experiments.

All of the muscular conditions upon which the resting postures are dependent are accentuated by activity. The robber flies move in circles by farther flexing the legs on the side of the functioning eye and extending those on the side of the blackened eye. The head bends farther toward the center of the circle and the abdomen curves so that the body is concave, forming an arc of the circle in which movement is executed.

2. Illuminating one eye. Bringing one eye of *Proctacanthus* into the bright beam of light directed through the objective of the optical system of the string galvanometer, while the other eye is illuminated only by the subdued light of the optical room, promptly produced the same postural relations described in the previous section. In this case the diffusely illuminated eye corresponds to the blackened eye. The result is due simply to a difference in the intensity of illumination of the two eyes. Mast[8] has produced similar tonus differences by reflecting light from a small mirror on one of the eye spots of *Arenicola* larvae; the body musculature contracted on the brightly illuminated side. This observation we have repeated and noted further that the contracted state persists as long as the light is held on the eye spot. The same curvatures have been noted by us when the constant current is passed transversely through the body of the marine worm *Podarke* and have also been described by Moore and Kellogg for the earthworm.[9] The general mechanism is the same for the action of light and the galvanic current.

3. Blackening the lower half of both eyes equally results in a symmetrical position of the legs of the two sides but the anterior and middle pair are extended forward to the maximal extent, producing a striking posture in which the anterior end of the robber fly is pushed up and back from the surface of the table. The front pair of legs may even be poised up in the air. The body is in opisthotonus with the abdomen concave on the dorsal side, while the head is tilted far up and back on the long axis of the body. The whole posture is that assumed by *Amblystoma* or by *Palæmonetes* as described above, when subjected to the influence of the constant current with the cathode at the anterior end. Holmes showed similar postures for *Ranatra* with a light placed above and posterior to the animal.

When walking these robber flies gave the impression of trying to climb up into the air. The wings are frequently somewhat spread and the

animal may push itself up and back until poised vertically on the tips of the wings and abdomen. The tendency to fly is very pronounced in this condition and upon the slightest disturbance the fly soars upward and backward, striking the top of a confining glass dish or completing a circle by "looping the loop" backward. If it falls upon its back it rights itself by turning a backward somersault. Unequal blackening of the lower parts of the two eyes results in a combination of the effects just described, with those described for blackening one eye, for the animal also performs circus motions.

4. *With the upper halves of the eyes blackened* the attitude is the reverse of that described in the preceding section. The anterior and middle pairs of legs are flexed. The anterior and posterior ends of the body bend ventrally with the body in emprosthotonus. The head is bent far down until its anterior aspect is parallel to the surface of the table. The animal may actually stand on its head, but the abdomen retains its ventral curvature, leaving a considerable angle open between its dorsum and the wings which normally rest on it.

In both walking and flying it continually keeps close to the table, and upon encountering an obstacle it frequently does a forward somersault. If it gets on its back it rights itself with greatest difficulty as its efforts simply result in bending the tail and head ventrally until they may form a complete ring. In galvanotropism the same general picture is presented by *Palæmonetes* and *Amblystoma* when the anode is at the head end, the tonus changes involved being identical in the two conditions.

5. *By blackening the upper half of one eye and the lower half of the other*, circus motions are performed toward the side with the lower half blackened. If for example the lower half of the right eye and the upper half of the left eye of the robber fly are blackened flexion of the anterior leg on the right side results. There is extension of the anterior leg on the left side. The body is thus somewhat twisted on its long axis for there is also flexion of the posterior leg on the left side and extension of its mate on the right side. Such a bizarre effect is hardly explicable by any recourse to the assumption that the animal is "avoiding the darkened field." In reality the tilting of the body and the twist of the head are toward the blackened part of the eye viz., *down* on the side on which the lower half of the eye is blackened, and *up* on the side on which the upper half has been blackened. The result is readily explained on the basis of a crossed innervation from the eyes to the extensor muscles of the opposite side, a view for which much evidence is at hand.

6. *Blackening corresponding halves of both eyes of Proctacanthus*, for example, the outer half of the right eye and the inner half of the left eye, causes postural changes similar to those produced by blackening all of one eye (the right) and circus motions away from the side to which the black has been applied, i.e., to the left in our example. This statement of fact is, however, capable of overemphasis for the intensity of the reaction depends upon the relative amount of black applied to each eye, thus if a greater area of the inner side of the left eye be blackened or a lesser area on the outer (right) side of the right eye the tendency to move in a circle to the left is lessened, nullified, or even reversed by combining the two procedures. This fact is an interesting and fatal contradiction to the view that the postures are assumed, and the circus motions made, in an attempt "to avoid the dark field which appears as an obstruction to the path." The reaction is a quantitative one and depends on the relative areas blackened as much as upon the part of the eye covered. The space relation of light fields to dark fields, does not change in the above experiment but the tonus of the muscles does change with the change in the areas blackened, whereby the behavior of the robber fly is reversed and it circles toward the side on which both eyes have been blackened.

When either the inner halves or the outer halves of both eyes are blackened, the muscles of the two sides remain absolutely symmetrical provided the eyes are equally and symmetrically painted. If the painted area is considerably less on one eye than on the other, the tonus changes again approach those found by blackening all of one eye and the animal, in walking, circles to the side with the greater area exposed to the action of light. Complete blackening of both eyes results in marked relaxation of all the musculature, although the two sides are symmetrical.

7. All the experiments show that the muscle tone is dependent upon the intensity of the light and that the postures assumed depend upon the relative differences in the illumination of the eyes. In animals with one eye completely covered the radii of the circles in which they moved were shorter the more intense the illumination of the normal eye. With one eye partially covered the circles were larger than when completely covered and in the same way, the circles were larger when one eye was covered by a film of collodion or of brown shellac, which admit some light, than when subsequently covered by opaque asphalt black. When one eye was partially covered by central application of the black paint the tilting and circling to the opposite side were abolished or reversed by brilliant illumination of the partially blackened eye. These re-

sults explain why a positively heliotropic animal with one eye blackened approaches a light by a series of alternating small and large circles, the former being executed when the good eye is illuminated from the source of light, the larger when it is in the shadow.

8. Differential sensibility. Robber flies with one eye blackened show the postural conditions in the most pronounced way in the early morning or after being kept for some hours in the dark. Constant exposure to the light produces considerable fatigue of the eye with recovery in the dark. These facts among others suggested the possibility of producing a different sensitiveness of the two eyes and corresponding differences in the muscle tonus with asymmetry of position, and in physiological action of the muscles of the two sides of the body when the two eyes were equally illuminated. Such an experiment constitutes a crucial test of the tonus theory of heliotropism. It succeeded beyond our greatest expectations. Asphalt black was applied to the right eye of several specimens of *Proctacanthus*. In two or three days the paint had formed a brittle shell. During this time the blackened eye had become 'dark adapted.' When such a fly is exposed to light, it tilts and circles to the left. If now the brittle shell is cracked off the right eye by carefully pinching with fine forceps, the exposure of this very sensitive eye to light results in a reversal of the whole picture; the fly circles toward the side from which the black was removed. Although the illumination of the two eyes is of equal intensity, what was the normal eye now becomes relatively a darkened eye owing to its lesser sensitiveness. A differential effect results, probably due to a difference in the rate of photochemical change in the two eyes. This reversal of the muscle tonus, and of forced motions, may persist for an hour or two or even longer, until the two eyes become, as they ultimately do, of equal sensitiveness and the fly behaves like a normal animal.

These experiments are not only incompatible with any avoidance idea, for after removal of the black there is nothing to avoid, but they are also incompatible with the conception of 'habit formation,' for "habit" in the performance of the circling movements is of no avail when light is admitted to the darkened eye. The animals circle to that side because the tonus of the muscles is such that they are forced to do so.

9. Post mortem rigor. *Proctacanthi* kept in a moist atmosphere but without animal food, have lived two or three weeks. During this time if one eye was blackened the tonus change in the muscles became almost a fixed condition, probably the result of an atrophy of the muscles or a lack of tonus, similar to the effects of disuse. Death supervening, the

onset of rigor exaggerated the condition existing prior to death and the animal stiffened in the characteristic postures. This follows the rule for rigor mortis, that the more strongly acting muscles contract more strongly after death. This fact lends additional proof for the tonus theory of the tropisms.

Conclusion.—These experiments remove, in our opinion, the last doubt that the motions of animals to or from a source of light are due to an influence of the light on the tension of muscles of different sides of the body whereby the animal is automatically carried to or from a source of light.

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CHANGEABLE COLORATION IN BRACHYURA

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Although changes in coloration have been observed commonly in crustacea, only two recorded cases appear to refer to Brachyura. Fritz Müller reported to Darwin[1] that the male of a Brazilian species of *Gelasimus* is subject to rapid and remarkable changes in appearance. R. P. Cowles[2] has also described changes in color in *Ocypoda arenaria* Say, which he believes are in the main, if not entirely, dependent upon changes in the intensity of the light and variations in the temperature to which the creatures are exposed. It would seem, however, that crabs are able at least to change their shade much more commonly than recorded observations would indicate and that other factors than those suggested may determine their coloration at a given moment.

Portunus depressifrons Stimp., *Callinectes ornatus* Ord. and *C. marginatus* A. M.-Edw. display striking changes in coloration under certain conditions. Others less obvious or less closely studied have been noted too in *Portunus spinicarpus* Stimp. and *P. sayi* Gibbes and in

Euryplax nitida Stimp., all of which as well as those mentioned above have perhaps been overlooked because they are much less apparent in mature than in immature specimens. It is also clear that in *O. arenaria* as well as in the six species last enumerated, the shade of the substratum plays a very important part in determining that of individuals resting upon it, since in each within a few minutes, usually less than ten, at temperatures commonly prevailing in the laboratory it is possible to reverse the shade of the two members of an adapted pair simply by transferring each to the dish occupied by the other.

Light colored crabs, essentially white ones, may be cooled in white dishes from temperatures between 30° and 35°C. to 12° and be completely paralyzed by the cold without changing in the least in shade. Crabs whose shade is adjusted to that of light and dark colored dishes respectively may be transposed at a temperature at least as low as 16°C. and have their coloration reversed as definitely as under warmer conditions. Cool crabs in dark dishes may be heated to approximately 35°C. before they commence to show any effect of the treatment. At higher temperatures, which vary in individual cases, they are blanched. At such temperatures it is also impossible to induce darkening, or at least the development of a distinct pattern, by transposing a light crab to a dark dish. Hence it is apparent that temperature is not the basic factor concerned in the matter, but merely one that limits adaptive color changes in *Ocypoda* near the upper level at which it is able to survive. It is possible, indeed, that the very appearance of heat-blanching indicates the abnormality of the situation, for, regardless of the shade of the substratum, a similar effect follows when the water in which the crabs are is charged artificially with CO_2.

The degree to which *Ocypoda's* coloration is independent of temperature may be demonstrated most strikingly in a single experiment by transposing specimens which have been standing in cold white dishes and warm black ones respectively. In a specific instance the coloration of two crabs was reversed without that one which was turning from dark to light ever becoming warmer than 17°C., or the other cooler than 35°. Equality of shade was attained in twenty-nine and complete reversal in about fifty minutes. Thus it is plain that temperature is so much less effective than the shade of the underlying bottom in determining coloration that the latter is able to induce adaptive changes in opposition to Cowles's laws in the face of a temperature difference of not less than 18°C. The time relation established, however, does not represent the minimum required to effect the change, since the water in the dark dish was for a time above the temperature at which heat-

blanching appears, and the darkening of the crab in it was therefore delayed.

It does not seem to be true, as has been suggested by Dr. Cowles, that the "blanching of individuals on the sands of Loggerhead Key is probably due to high temperature alone," or that during a large part of the time Ocypoda would be heat-blanched rather than adaptively colored. He observed that water standing outside the laboratory was heated to 45°C., at which temperature experiment shows that the substratum exercises a negligible effect in determining the crabs' coloration. Even higher temperatures than that recorded may occur, but this fact has only a slight bearing upon the matter at issue, for this excessive heat does not characterize the creatures' environment when they are exposed.

The animals live and feed largely in the zone below high water mark, where actual observation twice showed a temperature of 39°C. when the same thermometer lying flat in the same way on the sand 25 feet above it registered 49° and 45° respectively on the two occasions. It may also be demonstrated readily by raising the instrument half an inch on crotched sticks that the temperature prevailing at the level at which an active crab's body would actually be is considerably lower than on the sand, being 37° and 36.5° in the two cases cited. That is to say, at the hottest time in the day the temperature throughout the normal range of active crabs is very little above the minimum at which heat-blanching occurs. But at these times very few crabs are out of their burrows: five were digging them or standing idly in their mouths in the first case and only one in the second, while none at all were moving about freely over the sand where dozens might be seen both earlier and later in the cooler parts of the day. It is clear, therefore, that, unless their reactions to air and water temperatures are not the same, when the animals are actually exposed to the attacks of enemies, temperature is not sufficiently high to inhibit the effect of the substratum in inducing adaptive color changes which might reduce their conspicuousness.

So far it is apparent that the inference that adaptive color changes occur in the species mentioned rests wholly upon the demonstration of their ability to effect such changes in the laboratory. Similar adjustments are made, however, under natural conditions. It was, indeed, observation of the fact that, as one walks along a beach on which there is striking contrast between the dark and light patches covered by shallow water, the individual young *Callinectes marginatus* and *ornatus* that dart away from under foot differ in shade according as they start up from one or the other, that attracted attention to the possibility that such relations exist as have been reported in this article.

There is then every indication that further study will show that the colors of crabs and their capacity to change them vary from species to species according to the same general rules that appear to prevail among fishes.[3] But if in two groups of animals so widely separated the same laws of coloration prevail, and if the observed facts point so unanimously to the concealing function of coloration in each, it becomes increasingly improbable that other laws prevail as extensively as has been supposed among other animals, and increasingly evident that adaptation of the organism to its environment is one of the most striking of natural phenomena.

[1] Darwin, C., *Descent of Man*, Chap. 9.
[2] Cowles, R. P., *Washington, Carnegie Inst., Pub.*, No. 103, 1908, (1-41).
[3] Longley, W. H., *J. Exp. Zoöl., Wistar Inst. Philadelphia*, 23, 1917, (536–601).

THE EQUILIBRIUM OF TORTUGAS SEA WATER WITH CALCITE AND ARAGONITE

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The question of the solubility of calcite and aragonite in sea water is a matter of interest in relation to the geology of limestone and dolomite. Murray and Hjort[1] maintain that sea water is so complicated a mixture that the solubility of $CaCO_3$ cannot be calculated with certainty (from the law of mass action) but that the experiments of Anderson and of Cohen and Rahen show that sea water is saturated with calcite. They add, (p. 181) that dolomite is less soluble than calcite in carbonated waters. Their book summarizes observations showing that calcium carbonate is precipitated in shallow tropical waters, but that even shells are dissolved in the red clay bottoms of the depths.

Mayer[2] placed pieces of *Cassis* shell in sea water for more than a year and found them to maintain their weight within about $\frac{1}{10}$ of 1%. The precipitation of $CaCO_3$ at Tortugas was studied by T. Wayland Vaughan, R. B. Dole, and G. H. Drew.[3] Drew observed that a denitrifying bacillus, *Pseudomonas calcis*, obtained from the sea water, was capable of changing calcium nitrate to calcium carbonate in culture media and supposes a similar process to occur in sea water. Since Vaughan has observed that calcium carbonate is constantly precipitating at Tortugas, Drew's hypothesis necessitates the presence of an appreciable amount of nitrates or nitrites, and I have attempted to determine them.

A half liter of sea water was boiled in an all-glass still and the distillate collected in a series of 25 cc. Nessler's tubes. Another series of Nessler's tubes were filled with a graded series of concentrations of ammonium chloride. One cubic centimeter of Nessler's reagent was added to each tube and agitated. After fifteen minutes, the tubes were compared colorimetrically and the ammonia recovered from the sea water was estimated. After no more ammonia could be distilled from the sea water, amalgamated aluminium shavings were introduced into the still and the distillation process repeated. The ammonia recovered was formed by reduction of nitrates and nitrites. Duplicate analyses gave less than 0.01 mgm. of nitrogen per liter as ammonia and less than 0.01 mgm. nitrogen per liter as nitrates and nitrites. Raben found more than ten times these quantities in North Sea water.[4] Evidently, *Pseudomonas calcis* and other organisms have almost completely removed the fixed nitrogen from Tortugas sea water. The effect of this probably explains the scarcity of life in the vicinity of Tortugas as compared with colder seas (law of minimum). There is, however, a constant renewal of fixed nitrogen from the atmosphere, from the decay of organisms and probably from water rising from the depths of the ocean. If *Pseudomonas calcis* is an important agent in the precipitation of $CaCO_3$, its action is evidently more intense in places where calcium salts, nitrates and nitrites are carried from the land into the sea.

That calcium carbonate is withdrawn from surface waters of the sea, is shown by chemical analyses. Dittmar[5] found an average of 0.44% less calcium in surface waters than in deeper waters. This is true notwithstanding the fact that calcium carbonate is constantly being added to the surface waters. The drainage of the land contains an excess of calcium carbonate and flows out on the surface of the sea, where the water evaporates leaving the excess of $CaCO_3$ in the sea water. The action of organisms in building calcareous structures may account for a large part of the depletion of surface waters, but the precipitation of calcareous mud at Tortugas has been observed by Vaughan.

The analysis of the calcium content of sea water requires double precipitation, and filtration for separation from magnesium and hence large samples and great care are required for accuracy. Theoretically, however, we may detect differences in calcium content by titration. Dittmar showed that except for H_2O, calcium and gases, sea water is remarkably constant in composition. The water content may be determined by titration of the chlorides and the gases may be eliminated by boiling after the addition of enough acid to decompose the carbonates. If we disregard carbonic acid, there is an excess of bases

in sea water, i.e., the sum of the base equivalents is greater than the sum of acid equivalents. Since calcium is added to or taken from sea water in the form of $CaCO_3$, and change in the calcium content causes an equivalent change in the excess base or alkaline reserve, as it is called by chemists. The alkaline reserve may be titrated while boiling the sea water to eliminate CO_2. The exact value of the titration depends on the indicator used and the exact color of the indicator that is taken as the end point, hence only those titrations done in the same manner can be strictly compared. The titrations, used for the present paper were made by adding di-brom-o-cresol-sulphone-phthalein to 100 cc. of sea water in a flask of resistance glass and titrating with 0.01 *N* HCl, while boiling, until the purple color changed to yellow and did not become purple again after boiling for 5 minutes longer. The sides of the flask must not be allowed to dry as this would cause HCl to escape from the chlorides, due to the action of Magnesium. The results per liter were recorded and some titrations were made at 20° and others at 30°, but the errors due to change in volume of the sea water is within the limits of accuracy of the method. If the sea water is diluted with rain water, the alkaline reserve will be lowered, but this error may be compensated by dividing by the chlorine content (grams chlorine per kilogram sea water). In other words: a change in the quotient of the alkaline reserve by the chlorine per cent indicates a gain or loss of $CaCO_3$.

	ALKALINE RESERVE	Cl ‰	$\frac{\text{Alk. res.}}{\text{Cl ‰}} \times 10{,}000$
Sea water from San Diego, Cal.	0.00235	18.7	1.257
Sea water from Woods Hole, Mass.	0.00240	17.7	1.356
Gulf Stream, off Miami, Fla.	0.00250	19.9	1.257
Gulf Stream, off Tortugas, Fla.	0.00250	19.9	1.257
Average, Tortugas, June and July.	0.00247	20.0	1.235
Average, Key West, June and July.	0.00237	20.0	1.185

The above table indicates that some $CaCO_3$ has been removed from Tortugas sea water, as compared with other sea water, and to a greater extent from Key West sea water. In other words, the precipitation observed by Vaughan is not due to a greater amount of calcium in Tortugas or Key West sea water but to local conditions which cause the precipitate to form.

According to the law of mass action, in a saturated solution of $CaCO_3$ in sea water at constant temperature, salinity, etc.,

$$[Ca^{\cdot\cdot}] \times [CO_3''] = \text{a constant.}$$

Not all of the calcium is, however, in the form of $CaCO_3$ and $Ca^{\cdot\cdot}$, for some is undissociated $CaCl_2$, $CaSO_4$, $Ca(OH)_2$, and $CaHCO_3$. The chlorides and sulphates are constant but $[CaHCO_3]$ and $[Ca(OH)_2]$ change with the total CO_2 content of the sea water. But I have shown[6] that if the alkaline reserve remains constant, the total CO_2 of sea water (within limits found in nature) varies inversely with the pH (= − log.$H^{\cdot}$ concentration). Hence the determination of the pH may be substituted for that of the total CO_2. The determinations I have made of the water of the Pacific and North Atlantic showed the pH to vary from about 8.1 to 8.25 and those of Dr. A. G. Mayer in the Pacific showed only a little wider range (below 8). Earlier observations at Tortugas gave the same range, but my more extended observations made this summer demonstrate the inadequacy of a few determinations. The pH is influenced by plant and animal life and rises at Tortugas to 8.35 during the day over well-lighted bottoms rich in vegetation, and falls to 8.18 during the night. It may be said, therefore, that conditions in shallow water over eel-grass or other sea-weed or corals (with symbiotic algae) favor the precipitation of $CaCO_3$.[7]

The question arises whether the occasional high pH of Tortugas sea water is sufficient to explain the precipitation of $CaCO_3$, or whether nuclei for the separation of the solid phase are necessary. A large amount of $CaCl_2$ may be added to sea water without causing a precipitation. If the pH is increased by the addition of NaOH, the result depends on the speed at which the alkali is added. If the NaOH is added suddenly in the form of a strong solution, colloidal precipitation membranes form about the drops and if the membranes are broken by shaking or stirring, a great mass of $Mg(OH)_2$ is included in the precipitate. If a very dilute solution of NaOH is added very slowly, $CaCO_3$ possibly contaminated with $Mg(OH)_2$, is precipitated. The exact pH at which precipitation first occurs cannot be determined by this method as the first precipitation occurs before the solutions are mixed and the crystals thus formed serve as nuclei for further precipitation. If Tortugas sea water is kept in glass bottles, precipitation occurs on the glass while the pH of the water is within the natural limits, but the pH at the glass surface is higher, due to solution of glass.

Although the pH at which precipitation would occur without nuclei for the separation of the solid phase, may be practically impossible to determine, the final equilibrium with an abundance of nuclei is not a difficult problem. Calcite and aragonite crystals to serve as nuclei were produced by the methods of Johnston, Merwin and Williamson.[8] The crystals were examined under the microscope and tested with cobalt

nitrate solution. These observations, together with the mode of preparation, leave little doubt that the crystals actually were calcite and aragonite. Under the microscope an occasional calcite crystal could be found among the aragonite crystals but the number was not sufficient to affect the cobalt nitrate test. These calcite crystals apparently grew slightly during the experiments but apparently no new ones were formed. To determine the equilibria, crystals were mechanically stirred or shaken with sea water in 'nonsol' flasks, six to fourteen hours at 30°, then the pH and alkaline reserve determined.

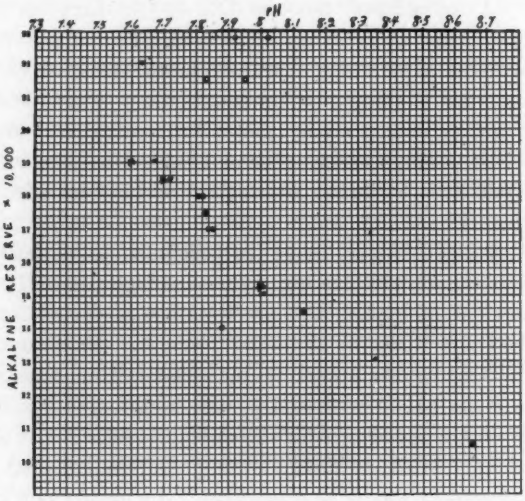

FIG. 1

The results are shown in figure 1. The alkaline reserve is measured on the ordinate and the pH on the abscissa. The results of agitating 100 grams of calcite crystals with a liter of sea water until equilibrium was approximately reached are shown by black rhombs in figure 1. If we draw a straight line from the intersection of the ordinates of pH 7.3 and alkaline reserve 0.0023 to pH 8.8 and alkaline reserve 0.0009, the determinations with calcite will fall very close to it. This shows that sea water of the surface of the oceans of the whole world is supersaturated in respect to calcite. We may therefore conclude that suitable nuclei for the precipitation of calcite are absent or deficient in number. The solubility of crystals varies inversely with their size, but after they have attained sufficient size to be readily examined with low powers of the microscope, further increase has an unappreciable effect on solubility. But such crystals if present, would be rapidly precipitated to the bot-

tom of the sea, hence the absence of nuclei for precipitation of calcite is what one might expect.

Aragonite is said to be about 10% more soluble than calcite, but no difference in the point of equilibrium of the two substances with sea water was detected in these experiments. This may be explained by the facts that a few calcite crystals were mixed with the aragonite, equilibrium was only approximated and there were slight errors in the determinations. The results are shown by black rosettes in figure 1.

During the rough weather, white calcareous mud is stirred with the sea water at Key West and to a lesser extent at Tortugas, and it was thought possible that the mud granules might form nuclei for precipitation and explain the low alkaline reserve at Tortugas and lower alkaline reserve at Key West. On agitating white calcareous mud, dredged from the bottom, with sea water, no definite equilibrium was reached, even at the end of four days. If the alkaline reserve was first lowered by removal of some $CaCO_3$, it remained lower than if shaken with calcite and if normal sea water was used the alkaline reserve remained higher than with calcite. It was thought possible that the grains were covered with an impenetrable film of organic matter; so some mud was dried and powdered in a mortar in order to break the pieces and form fresh surfaces, but similar results were obtained with this. The results are shown by black circles in figure 1.

If mud was mixed with an equal weight of calcite, the results were the same as with pure calcite, as shown by the black dumb-bells in figure 1. This mud and calcite on standing in sea water for thirty days had not changed to calcite. All these facts tend to show that the particles in the mud are in some way retarded or prevented from getting into equilibrium with the water.

In order to be sure of clean surfaces of natural calcareous substances, a specimen of coral, *Maeandra clivosa*, was ground and powdered in a mortar and agitated with sea water in the same manner as in previous experiments. The results were similar to those with mud, as shown by the white circles in figure 1.

There seems to be a more soluble form of calcium carbonate (the μ $CaCO_3$ of Johnston), but since it cannot be obtained in a pure state, no attempt was made to prepare it. One experiment, however, was made with a precipitate of $CaCO_3$ that appeared as spherical grains under the microscope. It was agitated for twelve hours with sea water and the alkaline reserve was 0.0022 at pH 7.95. No further experiments were made to determine whether equilibrium had been approximated.

These experiments clearly show that the surface water of the sea is a supersaturated solution of $CaCO_3$ and it is only necessary to introduce calcite crystals in order to cause considerable precipitation of this substance. Precipitation goes on in the bodies of organisms in the surface waters of all seas. The precipitation observed by Vaughan at Tortugas is very finely divided, but whether it was formed in the bodies of minute organisms, which subsequently died, has not been determined. Such particles might slowly grow, since the agitation of them with sea water was found to take a trace of $CaCO_3$ out of the water. Small crystals have been seen in the bodies of Protista, and whether they are $CaCO_3$ or not, they might form nuclei for the precipitation of $CaCO_3$ if released into the sea water.

In some experiments in liter flasks of resistance glass, filled into the neck (and hence admitting of but slight loss of CO_2) the pH and alkaline reserve was determined immediately before and after agitation with calcite, and the loss of CO_2 from the sea water calculated from the pH and from the loss of $CaCO_3$ (alkaline reserve).

SEA WATER	pH	TOTAL CO_2	ALKALINE RESERVE	CALCULATED LOSS OF CO_2	
				From pH	From alk. res.
Before agitation with calcite	8.2	44.5	0.0025	6	6.72
After agitation with calcite	7.67	38.5	0.0019		
Before agitation with calcite	8.25	43.8	0.00250	6.8	7.27
After agitation with calcite	7.72	37.0	0.00185		

In the above table, the agreement is very striking in view of the probable error in determination of pH and the liability to loss of CO_2 from the water surface in the neck of the flask, agitated by the rotary stirrer.

If the pH of sea water should be maintained (by the action of plants) at 8.2 while it was agitated with calcite crystals, the loss of $CaCO_3$ would be about 0.001 N, or 0.0005 M, or 0.1 gram per liter. This would cause a deposit of 10 kgm. per square meter of bottom in water 100 meters deep. This would cause a lowering of the calcium content of Tortugas sea water by about 4.5%.

[1] *The Depths of the Ocean*, London, 1912, p: 178.
[2] These PROCEEDINGS, **2**, 1916, (28).
[3] *Washington, Carnegie Inst.*, Pub. No. 182, 1914, (Tortugas Lab., vol. 5).
[4] *Depths of the Ocean*, p. 368.
[5] *Voyage of H. M. S. Challenger, Physics and Chemistry*, vol. 1.
[6] McClendon, *J. Biol. Chem.*, Aug., 1917.

[7] It would be interesting to know whether corals and calcareous algae deposit as much $CaCO_3$ in the dark as in the light. Corals from deep water are smaller, more fragile, and deposit less $CaCO_3$ than those of shallow water, but the same is true of animals without symbiotic algae. The deposition is, however, related to the pH, since Palitzsch has shown that the pH decreases with depth.

[8] *Amer. J. Sci., New Haven*, **41**, 1916, (473).

AN OENOTHERA-LIKE CASE IN DROSOPHILA

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Although the large bulk of the Drosophila work has been remarkably self-consistent, and amenable to orderly and definite rules of factor transmission, yet from the outset the ideal scheme has been confronted with two unconformable cases. These are the cases of beaded wings and of truncate wings, both of which seemed to belie the idea of clear cut segregating gens. In the case of beaded wings, which will be briefly reported here,[1] many generations of selection were carried out by Morgan with the purpose of obtaining a pure breeding stock, yet for several years it was impossible to attain this object. The character showed all the peculiarities which would be expected as a result of factor fluctuation and miscibility. It was increased in intensity as a result of selection yet its essential variability remained, and the latter was proved by crosses to be genetic, for Morgan found that reversed selection produced a marked and immediate retrogression in the proportion of beadeds thrown. Finally, however, he did obtain a race which threw no normals, but the reason for this change in behavior seemed now just as difficult to discover as the cause of the previous variability. On crossing, various apparently irregular results and aberrant ratios followed.

The work of Dexter, which showed that environmental conditions and factors in both the second and third chromosomes are all concerned in the development of this character, provided valuable information for the present investigation. Starting from Dexter's finding that there was a chief factor for beaded in chromosome III[2] an attempt was made by the writer to find the precise location of this gen. It proved to lie at the extreme right hand end of the known factors in the third chromosome, being two and a half units beyond the factor for rough eyes, which is otherwise the furthest factor to the right. It was found also that the apparently pure beaded stock is not homozygous for beaded, but in reality contains two very different kinds of third chromosomes. It was by investigating this phenomenon, with the aid of the data secured in

the linkage study, and by dissecting, by means of crossing over, each of these two kinds of chromosomes separately, that a complete explanation of the beaded case was finally obtained. It would be impossible here to give even an outline of the detailed steps of analysis, but the following are the concrete results and theoretical conclusions which have been arrived at.

1. The difficulty which was experienced in getting pure stock was due to the fact that the chief factor for beaded—B_d'—is lethal, killing all flies homozygous for it. Heterozygous beadeds are not killed but usually show the beaded character. Thus B_d', like yellow in mice, is dominant for its visible effect and recessive for a lethal effect. The dominance of B_d' is variable, however.

2. The reason that a race which bred true to beaded was finally secured is not because a condition of homozygosis was at last established, but, on the contrary, because of the establishment of a state of enforced heterozygosis, wherein not only the homozygous beadeds but also the homozygous normal winged flies were prevented from hatching. This was due to the appearance, by mutation, of another lethal factor, $l_{III\,1}$, in that third chromosome of the impure stock which contained the normal allelomorph of B_d'. This lethal, like B_d', kills all flies which are homozygous for it, although, unlike B_d', it has no visible effect when it is heterozygous. Since, in the flies of this heterozygous race, it arose in the chromosome containing the factor for normal wings, no homozygous normals will be able to appear except those in which $l_{III\,1}$ has been separated by crossing over from the normal allelomorph of B_d'. The usual amount of crossing over between these loci of $l_{III\,1}$ and of B_d' is 10%, as $l_{III\,1}$ was found to be 10 units to the left of B_d'. On this basis it is to be expected that the selected beaded stock would throw 90% beaded flies and 10% normal winged crossovers.

3. In this selected stock, however, not even 10% of the flies have normal wings, because of the existence of another mutant factor, C′, which almost entirely prevents crossing over in the region of the chromosome in which $l_{III\,1}$ and B_d' lie. $l_{III\,1}$, on this account, always remains with the normal allelomorph of B_d' and all the homozygous normal winged, as well as the homozygous beaded flies are thus prevented from appearing. It should be noted that the factor C′, too, always remains heterozygous, for it is contained only in the chromosome having $l_{III\,1}$ and the normal allelomorph of B_d', not in the chromosome with B_d' itself. This state of heterozygosis for C′ is also a necessary condition for the mechanism whereby only beaded flies are produced, since C′ produces its inhibition of crossing over only when it itself is heterozygous. Aside

from its influence on crossing over, no other effect of this factor has been discoverable. The locus of C′ is within 10 units of that of sooty body color, being to the left of the locus of $l_{III\,1}$, and to the right of the locus of kidney eyes. C′ probably existed in the chromosome of beaded stock now containing it before $l_{III\,1}$ arose in that chromosome by mutation.

4. This remarkable genetic situation, wherein both types of homozygotes are prevented from appearing by the action of lethal factors lying in opposite chromosomes, may be termed a condition of 'balanced lethal factors.' Surprising as it may seem, it appears that such a condition is no mere 'freak of nature,' and that it is apt to arise wherever dominant mutant factors exist which either have some natural survival value, or have, like beaded, been artificially selected for. This conclusion is based upon the following experimental results and theoretical considerations.

(a) In an attack upon this question, an investigation was undertaken by the writer to determine how generally dominant mutant factors of Drosophila are lethal when homozygous. There were nine dominant mutants known (excluding the intensifiers of beaded and truncate), and they were distributed equally among the three large chromosomes. The viability of the three sex-linked dominants was, of course, already known; the remaining six dominants were tested. In all, it was found that three of the nine are not lethal, one (in chromosome III) is semilethal, and five (one in chromosome I, two in II and two in III) are completely lethal when homozygous. Thus it is a phenomenon of common occurrence in Drosophila for dominant mutant factors to be lethal when homozygous.

(b) It would be very far fetched to assume that the natures of the characters produced by dominant factors differ as a class from those produced by recessives. We must therefore believe that lethals are very frequent among recessive factors also. It should be noted, however, that in the case of recessive factors a lethal action prevents or greatly hinders their discovery, whereas with factors dominant in respect to some visible character, a lethal effect, when homozygous, does not interfere with their being detected; for this reason it is quite in accord with expectation that a much smaller proportion of lethals has actually been found among the recessives than among the dominant mutants. The evidence for the frequency of origin of recessive lethals is not entirely by analogy, however, for in the case of sex-linked factors the discovery of lethals is easier, owing to their effect upon the sex ratio, and here a considerable number of lethals has in fact been found, by

various observers. Following up, now, our original inference regarding the high frequency of lethals among recessive mutants, it should further be pointed out that since recessive mutants as a class are much more numerous than dominant mutants, recessive lethals also should arise much oftener than dominant ones.

(c) It now remains to join these two results together in one conclusion. Suppose that a race already contains a dominant mutant factor which is favored by selection. Firstly, as shown in (a), this is likely to be lethal when homozygous. Then, as shown in (b), it is likely that a recessive lethal will some time, in some line of individuals, arise by mutation in the opposite chromosome. Since the first factor is being selected for, and the presence of this second lethal will cause the production of a smaller proportion of individuals not showing the desired dominant character, the line containing the second lethal in addition will tend to be selected. Thus a condition of balanced lethal factors will automatically become established, just as it did in the case of beaded wings. Factors which prevent crossing over, or balancing lethals which cross over less frequently with the desired dominant, will of course also be favored by selection, provided they occur, for the less crossing over there exists between the two balanced factors, the more perfect is the balance and the greater is the proportion of individuals showing the advantageous character. The frequency of factors like C′ is however unknown, although they have been discovered in nearly a dozen stocks of Drosophila. In the case of the beaded stock, the presence of C′ seems to be just a happy coincidence, as it probably existed there before $l_{III\,1}$ arose. But, however that may be, it is evident that the present case is but a special instance of a general class of cases of balanced lethal factors that will probably confront the geneticist in increasing numbers.[3]

5. What will be the distinguishing characteristics of races in this condition? (a) In the first place, crosses of these varieties to other races will result in the production of hybrids of two types, according to which of the chromosomes of the balanced pair they receive. Thus, flies of beaded stock crossed to normal give 50% beaded and 50% normal in F_1. In cases where one of the lethal containing chromosomes is not dominant to the chromosomes of the foreign race in any 'visible' factor, one of these hybrids (in our case the normal) will appear to breed true, while the other will show segregation in subsequent generations. By introducing other mutant factors besides into the balanced chromosomes of beaded stock, these results were made more striking and made to apply to a number of different characters at once.

(b) Still more unusual results can be and were obtained by crossing a

balanced race with another which also contained lethal factors (either the same or different in nature and grouping). In such cases not only twin but also multiple hybrids may be produced, that may or may not be constant. The results, however, always came out according to the prediction based on knowledge of the factorial composition of the flies. One such result which was especially noteworthy was a prearranged cross in which a dominant character present in one of the parent flies was caused to disappear completely, being absent from all the progeny of the cross and all subsequent generations.

(c) A lowered productivity is of course noticeable in balanced races, owing to the action of the lethal factors.

(d) In stocks in which other recessive mutant factors had been introduced into one or other of the chromosomes containing the lethals, these factors, of course, usually failed to manifest themselves, owing to the enforced heterozygosis. Occasionally, however, one or more crossed over from the lethal factor with which it was bound, and so was enabled to become homozygous. As crossing over occurs with predictable frequencies, these individuals showing characters abnormal to the stock were thrown continually in a definite, very small per cent of cases. This caused the stock to appear 'eversporting.' Crossing over between the lethal factors themselves also occurred very rarely, giving rise to individuals no longer exhibiting the unusual genetic behavior due to balanced lethals.

6. The striking parallel between the above behavior and that exhibited in Oenothera make it practically certain that this, too, is a complicated case of balanced lethal factors, and that some (if not most) of the so-called mutations in O. lamarckiana are but the emergence into a state of homozygosis, through crossing over, of recessive factors constantly present in the heterozygous stock. Proof of the spuriousness of some of the mutations in Oenothera is, however, not an argument against the validity of the modern mutation theory; the fact of real mutation has been amply demonstrated in Drosophila as well as elsewhere, and it should be emphasized that these mutations can here be distinguished with certainty from the superficially similar phenomena that are observable in the beaded stock, because the genetic constitution of the flies can be analyzed in detail.

In Oenothera a form of the balanced lethal explanation was suggested by de Vries only to account for his double reciprocal crosses, but it is evident from the analogy of the beaded case that it probably lies at the root of nearly all the unusual genetic phenomena of the genus. The two cases differ in detail, however, in that one or more of the lethals in

Oenothera produce their effect upon the gametes, rather than upon the zygotes.

Double throwing stocks (Matthiola) present another case of balanced factors. This too differs in detail from the beaded case, for one of the factors acts very early, producing its lethal effect directly upon the gametes (pollen), as in Oenothera, whereas the other, although it affects the zygotes, does not act as a lethal to their soma, but merely causes their sterility. It is this factor which causes the double flower.

7. The condition of balanced lethal factors must slowly lead to a partial degeneration of the chromosomes containing these lethals. For any new lethal recessive factors that arise in these chromosomes will never have the opportunity of becoming homozygous and producing their harmful effect, and so there will be no cause for natural selection to eliminate them. Lethal recessive mutant factors of all sorts (including 'deficiencies') will therefore gradually accumulate in the chromosomes of the affected pair. Moreover, although $l_{III\ 1}$ is the first lethal recessive which has been found in an autosome of Drosophila, theoretical considerations and the experiments above reported lead to the conclusion that in the course of time the number of such mutations will have been not inconsiderable, as they probably form a large proportion of all the mutations that occur. For similar reasons, chromosomes of stocks which are continually outcrossed, and the Y-chromosome in all species containing it, should undergo degeneration, because these chromosomes, too, are always protected, by heterozygosis, from the action of natural selection.

8. Not only are mutants of an undesirable nature not eliminated from balanced chromosomes by natural selection, but recessive mutant factors of a desirable type also are prevented from becoming homozygous and producing their effects, and so they cannot be selected for. On account of this latter circumstance, evolution is hindered in these varieties. As each chromosome of the balanced pair degenerates, however, it must gradually lose the dominant normal factors that prevented recessive mutant allelomorphs in the opposite chromosome from manifesting themselves. The balanced races might, moreover, eventually return completely to a condition of normal genetic behavior, owing to the occurrence of doubling or non-disjunction, which might make two normal pairs of chromosomes out of one balanced pair.

9. The inheritance of beaded is complicated not only by balanced lethal factors, but also by a modifiability of the character under the influence of environmental conditions, and by multiple factors. A number of the well known mutant factors for totally different characters

than beaded have been found to intensify or inhibit the development of the latter, and there is besides, as Dexter has shown, a factor in the second chromosome of the selected beaded stock itself which has no visible effect other than to increase the degree of beading. This must have arisen by mutation and have been perpetuated in the process of selection. Crosses made in the course of the present work have shown that this intensifier, I_{Bd}', is partially dominant, but is not a lethal, and, in contrast to the other factors involved in beaded stock, that it exists here in homozygous condition. At least one mutant factor has also been found, by the writer, which can produce a character similar to beaded even when the factor B_d' itself is not present; this mutant is not ordinarily present in beaded stock, however. All the facts of the present section may be summed up in the single generalization that beaded is a character depending upon a developmental reaction that is readily modifiable.

The complete formula of the selected beaded race, representing all the pairs of factors wherein it differs from the wild type, may now be given:

$$\frac{I_{B_d}'}{I_{B_d}'} \; \frac{c' l_{III\,1} B_d'}{C' l_{III\,1} b_d'}$$

10. The beaded case illustrates to great advantage the danger of confusing characters with gens and of drawing radical conclusions concerning the behavior of gens on the basis of uncritical experiments. The work of the first four years upon the inheritance of beaded wings gave evidence which would to many have appeared most elaborate and convincing, that the hereditary material in this case was fluctuating and miscible, consisting of vague and plastic "tendencies," rather than definite physical particles. Precise analysis, of a sort comparable to that of chemistry, has, however, been possible here, and it has demonstrated that a very different set of processes from those that might have been imagined is responsible for the peculiar results—processes which in their essence conform strictly to the genotype conception.

It will accordingly be necessary in other cases also not to accept evidence apparently in favor of factor inconstancy until factorial analyses of a similarly rigorous character have proved such an interpretation to be correct. A similar criticism applies to the acceptance of results that seem to be non-Mendelian; and also to the incautious estimation of apparent mutations at their face value. 'Non-Mendelian' results of all kinds and also 'mutations' may be prearranged and brought about at will with the beaded flies, but here analysis has made the

Mendelian machinery at work evident. Unwelcome as these conclusions may sound to obscurantists and to those in general who have an antipathy for exact modes of procedure, the necessity for such refined methods here should be obvious. In particular, it will be desirable to examine more intensively those cases which show the characteristics described in Section 5 for balanced lethal factors.

[1] The full account of this case will appear subsequently, and also an account, by Altenburg and Muller, of the truncate case.

[2] Sturtevant also had performed certain linkage experiments in which beaded was present; these showed that it was well on the other side of sooty from pink.

[3] Since the above has gone to press, a case in *Campanula* which may be due to balanced lethals has been reported by Miss Pellew in the *Journal of Genetics*.

IS DEATH FROM HIGH TEMPERATURE DUE TO THE ACCUMULATION OF ACID IN THE TISSUES?

By Alfred Goldsborough Mayer

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Communicated September 12, 1917

I find that there is a converse relation between the rate of oxygen consumption in reef corals and their ability to resist high temperature, those corals which are most readily killed by heat having the highest metabolism (rate of oxygen consumption).

NAME OF CORAL	CONSTANT TEMPERATURE EXPOSURE TO WHICH CAUSES DEATH IN ONE HOUR	RELATIVE RATE OF OXYGEN CONSUMPTION PER GRAM OF LIVING SUBSTANCE IN EACH CORAL
	°C.	
Acropora muricata	34.7	18.7
Orbicella annularis	35.60	6.1
Maeandra areolata	36.80	5.5
Favia fragum	37.05	3.8
Siderastrea radians	38.20	1.0*

* At 28.5°C. 1 gram of living substance of *Siderastrea radians* consumes 0.0256 cc. of oxygen per hour. The oxygen being measured at 0°C. and 760 mm. pressure.

Also, if sea water be super-saturated with carbon dioxide gas, the toxic effect is in the same sequence as that of high temperature. That is to say, those corals which are readily killed by heat are also correspondingly easily killed by H_2CO_3.

This toxic effect of carbon dioxide is not due to its replacing some of the oxygen of the sea water, for I find that corals are remarkably insensitive to a reduction in the oxygen supply, all species except *Acropora* living more than eleven hours in sea water under an air pump which reduced the oxygen to less than 5% of that of normal sea water; and even *Acropora* can withstand six hours of this treatment.

We know, indeed, from the studies of M. Henze that sea anemones use less oxygen the less its concentration in the sea water, and in 1917, J. F. McClendon found that the medusa *Cassiopea* can survive without apparent injury for more than seven hours in the absence of oxygen, and during this time does not give out CO_2. Thus these cœlenterates can temporarily suspend their metabolism for a protracted period if oxygen be absent.

Winterstein's theory that death from heat is due to asphyxiation appears to be refuted by these experiments.

E. N. Harvey, 1911, found that if the sea water be heated the rate of nerve conduction in *Cassiopea* augments in a right line ratio up to a certain point and then rapidly declines just before death ensues.

In 1917, I found that this temperature curve, up to its maximum point, has no time factor. That is to say, the rate at 35°C. is the same whether the medusa be placed at once in 35°C. or warmed slowly for several hours until it arrives at this temperature. Moreover, the normal rate for 29° is regained almost immediately when the medusa is replaced in this normal temperature.

When the rate is declining, due to injuriously high temperature, however, I find that a time factor is involved, the decline becoming more pronounced as the heat is continued. Also, if after this the medusa is replaced in sea water of 29°C., its former rate is much reduced and may never be recovered, although if exposure to the heat was not too long or the heat not too excessive, a slow recovery is usually observed so that after a few hours the rate may again become normal.

It will be recalled that Harvey, 1911, advanced the theory that some enzyme might be destroyed by the excessive heat, and being essential to nerve conduction, its loss caused the rate to decline.

Our experiments however make it seem more probable that some toxic acid substance, possibly lactic acid or H_2CO_3, is formed under the influence of excessive heat. It is easy to see how an acid of this sort might be eliminated and the rate gradually restored when the animal is replaced in normal sea water, whereas if an enzyme were destroyed it might not so readily be replaced.

In any event one or the other of the above mentioned hypotheses seems more in accord with the facts than does Winterstein's asphyxiation theory or the theory that death from heat is due to coagulation of proteid substances.

Death occurs at too low a temperature for coagulation in most if not all proteids; and when killed, the animals are fully relaxed as shown by Harvey. Moreover, coagulated proteins could not readily be eliminated when the animal was restored to water at normal temperature.

NATIONAL RESEARCH COUNCIL

MEETINGS OF THE EXECUTIVE COMMITTEE

The twenty-seventh meeting convened in the offices of the Council in the Munsey Building, Washington, D. C., on Wednesday, August 15, 1917, and was called to order at 6.00 p.m. by the Vice-Chairman, Mr. Millikan.

Messrs. Bogert, Millikan, Stratton, Vaughan, and, by invitation, Durand and Mendenhall were present.

Mr. Millikan presented a report from the Chairman of the Committee on Noxious Gases, recommending an additional appropriation of $662,900, which it is estimated will be required for gas warfare investigations for the fiscal year ending June 30, 1918. After discussion, these estimates for expenditures, which are additional to the original allotment of $175,000 recommended for such investigations at the meeting of the Executive Committee of the Council on May 28, were approved and the Vice-Chairman and Executive Officer of the Council were requested to transmit them with such approval to the Secretary of War and to the Secretary of the Navy.

The twenty-eighth meeting convened in the offices of the Council in the Munsey Building, Washington, D. C., on Wednesday, August 22, 1917, and was called to order at 9.10 a.m. by the Vice-Chairman, Mr. Millikan.

Messrs. Bogert, Carty, Chittenden, Millikan, Noyes, Pupin, Stratton, Vaughan, and, by invitation, Durand were present.

The minutes of the meetings of July 31 and August 15 were read and approved.

Upon motion the Committee approved the action of the Chairman of the Council in appointing a special committee to meet once a week to consider questions relating to the conduct of affairs of the Council in intervals between meetings of the Executive Committee; the membership of this committee to consist of Mr. Millikan, chairman, and Messrs. Bogert, Durand, Mendenhall, Stratton and Vaughan.

It was also voted that the minutes of the meetings of this special committee be duplicated and distributed regularly to members of the Executive Committee.

Explanation was made of the financial business of the Council and statements were submitted of the balances available in its three bank accounts.

Mr. Pupin invited discussion relative to relations which may exist between the National Research Council and the Engineering Foundation after the termination of the present agreement on September 20, 1917, by which the income of the endowment of the Engineering Foundation is made available for purposes of the Council. After lengthy discussion the following statement expressive of the appreciation and opinion of the Executive Committee in this matter was approved and ordered for transmission to the Engineering Foundation:

As the year for which the cooperative arrangement was made between the Engineering Foundation and the National Research Council will soon expire, the Research Council wishes again to record its high appreciation of the liberal financial and personal assistance which the Foundation and its members have afforded in the organization and support of the work of the Council in this first year of its existence. It seems exceedingly desirable to maintain the close relation between engineers and research workers which the Research Council has for the first time succeeded in establishing. Accordingly the Council wishes to express the hope that it may be practicable to continue some effective form of cooperation between the two bodies and it would be glad to appoint representatives to consider this matter with men designated by the Foundation.

Mr. Durand submitted a report from the special committee appointed at the meeting of the Executive Committee of July 31st to confer with representatives of the U. S. Patent Office with regard to the possible cooperation of the Council in questions of organization and conduct of affairs of this Office.

After extended discussion relative to the advisability of undertaking such work in the present national emergency it was voted, upon motion of Mr. Noyes, that the special committee in question be requested to confer with the new Commissioner of Patents, when appointed, to emphasize the importance of the proposed work and to state the willingness of the National Research Council to cooperate with the Patent Office in such effective ways as may be available; but at the same time to call attention to the large scope of the project and the inability of the National Research Council to cope with the financial considerations involved.

Upon motion it was decided to issue a new descriptive pamphlet relative to the work and organization of the Council, the Executive Officer of the Council being requested to appoint a special committee to consider and expedite this work.

Mr. Vaughan, as Chairman of the Committee on Medicine and Hygiene, presented the following resolution adopted by the Sub-Committee on Psychiatry of this Committee:

The nervous diseases grouped under the term 'shell shock' constitute a new and very important medical problem of war. They are responsible for fifteen per cent of discharges for disability from the British Army. Soldiers with these disorders present difficult problems in diagnosis and treatment and constitute a large proportion of those who after long continued hospital treatment become pensioners. These disorders in troops at the front are seriously prejudicial to discipline, morale and military efficiency. In spite of the extraordinary prevalence, very little is known about their physiological or psychological basis. The research which has been carried on since the war began has been seriously retarded by the stress of war conditions and little has been accomplished in any of the European armies.

As the American Army is certain to suffer no less severely from these disorders than the armies of our Allies, it is essential to secure without delay more information than we now possess as to their causes, nature and best methods of treatment.

With this object in view, it is resolved that the National Research Council be requested to permit this Sub-Committee to organize a Commission and to establish an experiment station in France for the study of 'shell shock' and to secure funds to meet the expenses of the work of this Commission.

Upon motion this request of the Sub-Committee on Psychiatry was approved, with the understanding that funds to meet expenses of the proposed work be secured from other sources.

Mr. Durand presented a request for an allotment of $250 for incidental expenses in connection with experiments being undertaken by Messrs A. M. Hunt and Cary T. Hutchinson on the production of artificial spray in which to envelop ships for purposes of protection. He pointed out that this investigation is a very promising one and has the approval and cooperation of the Ship Protection Committee of the Emergency Fleet Corporation. Upon motion, an allotment of $250 was made for this purpose, to be expended from the funds of the Council which have been deposited with the Engineering Foundation.

Mr. Bogert, Chairman of the Chemistry Committee, submitted a general statement relative to the work of this Committee, and upon his recommendation the following additional appointments were made to membership in Sub-Committees:

Sub-Committee on Chemistry of Fuels: W. A. HAMOR, W. E. VAWTER, and E. R. WEIDLEIN, all of the Mellon Institute of Industrial Research, Pittsburgh, Pa.

Sub-Committee on Chemistry of Leather and Tanning: F. P. VEITCH, U. S. Department of Agriculture.

Sub-Committee on Chemistry of Dye-stuffs: MARX HIRSCH, 50 East 41st Street, New York, N. Y.

Sub-Committee on Organic Chemistry: ROGER ADAMS, University of Illinois, Urbana, Illinois.

After discussion, upon motion of Mr. Noyes, it was decided to discontinue the Committee on Nitrate Supply of the Council and to organize a new Committee on Nitrogen Fixation as a Sub-Committee of the Chemistry Committee.

A report was read from the Chairman of the Psychology Committee descriptive of the organization and progress of psychological work which has been obtained in relation to military activities and, upon motion of the Chairman of the Committee, the following Sub-Committees were appointed:

Sub-Committee on Methods for the Psychological Examining of Recruits: Chairman, R. M. YERKES; W. V. BINGHAM, H. H. GODARD, T. H. HAINES, L. M. TERMAN, T. L. WELLS, G. M. WHIPPLE.

Sub-Committee on Tasks of Special Skill: Chairman, E. L. THORNDIKE; J. C. CHAPMAN, T. L. KELLEY, W. D. SCOTT.

Sub-Committee on Problems of Aviation, including the examination of aviation recruits: Chairman, H. E. BURTT; W. R. MILES, L. T. TROLAND.

Sub-Committee on Incapacity, Reeducation and Vocational Training: Chairman, S. I. FRANZ; K. S. LASHLEY, J. B. WATSON.

Sub-Committee on Visual Problems: Chairman, RAYMOND DODGE; R. P. ANGIER, H. A. CARR, L. R. GEISSLER, S. P. HAYES, G. M. STRATTON, L. T. TROLAND.

Communications received from the Chairman of the Geology and Paleontology Committee were presented and, after consideration, the following actions were taken:

EDWARD B. MATHEWS, of Johns Hopkins University, was appointed as Chairman of the Sub-Committee on Roads and Road Metals, to replace Dr. William B. Clark, deceased.

BASHFORD DEAN, Curator at the Metropolitan Museum of Art, was appointed a member of the Geology and Paleontology Committee.

A Sub-Committee was appointed, to be known as the *Pacific Coast Sub-Committee on Geology*, with the following membership: JOHN C. MERRIAM, Chairman; D. M. FOLSOM, J. C. JONES, HENRY LANDES, A. C. LAWSON, GEORGE D. LOUDERBACK, WARREN D. SMITH, BAILEY WILLIS.

The Vice-Chairman reported that W. P. Wilson, Director of the Commercial Museum, Philadelphia, Pa., has accepted appointment as a member of the Botanical Raw Products Committee of the Council, but that John C. Teeple has found it impossible to become a member of this Committee.

A statement was also read of the proposed work of this Committee, as well as a proposed budget of the annual expenses for the organization of such work.

Mr. Durand submitted a statement relative to the work of the Engineering Committee of the Council and referred particularly to consideration which has been given to the question of steel body armor and the probability that this work may be extended and organized.

Mr. Millikan submitted a report concerning the question of the detail of drafted men for special technical services in the army. He mentioned requests which have been received from France for groups of scientists to work in foreign laboratories and to undertake certain researches under the auspices of the U. S. Signal Corps. He reported that the following additional recommendations had been submitted to the Chief Signal Officer relative to the organization of work in meteorology and sound-ranging:

1. That Major E. H. Bowie be appointed American Forecaster in general meteorology in France to work in close cooperation with the French Military Meteorological Service, with headquarters which will probably be at Paris.

2. That Dr. William H. Blair be placed in full charge of the Aerological Service of the Army both in the United States and at the Front. It is understood that this work involves surface observations as well as upper air observations.

3. That after the preliminary organization of the aerological work in this country, as outlined in the subjoined recommendations, Dr. Blair proceed at once to France to study the conditions and organize the American Aerological Service there.

4. That Major Bowie proceed at once to France to begin work in connection with the French Forecasting Service.

5. That Mr. R. Hanson Weightman be commissioned as a First Lieutenant and assigned as an assistant to Major Bowie in forecasting work in France.

6. That Prof. Theodore Lyman be commissioned as a Captain and Mr. Norman R. French be commissioned as a Lieutenant in the Signal Corps, Sound Ranging Service, and that Major Trowbridge accompanied by the above officers proceed to France at the earliest possible moment and report to Colonel Russell.

7. That Dr. Herbert B. Williams be commissioned as a Captain in the Signal Corps, Sound Ranging Service, and that he be detailed to Princeton in charge of the construction work on sound ranging instruments during Major Trowbridge's absence.

8. That Mechanician William Duryea be taken into the employ of the Signal Corps at a salary of $1500 per annum and that Mr. Sanford P. Wicks now enlisted in the 3rd Ambulance Company, National Guards, State of New York, be transferred to the Signal Corps and assigned to mechanical work under Mr. Duryea and that Major Trowbridge be authorized to hire one other man as a mechanic at current wages.

The twenty-ninth meeting convened in the offices of the Council in the Munsey Building, Washington, D. C., on Wednesday, September 5, 1917, and was called to order at 4.30 p.m. by the Vice-Chairman, Mr. Millikan.

Messrs. Bogert, Carty, Dunn, Millikan, Stratton, Vaughan, and, by invitation, Colpitts, Durand, Manning, Mendenhall and Yerkes were present.

Mr. Millikan emphasized the importance of maintaining the Council as a centralizing agency for the activities of its committees and for the scientific interests which may be entrusted to it by various departments of the government. In this connection discussion took place relative to the detail of drafted men for scientific services in the army. Further discussion led to a consensus of opinion, which was recorded in the form of a motion, that, as a matter of policy in submitting requests for the detail of such men, it would be advisable to secure their services as privates with the understanding that additional request would subsequently be made for the appointment of a due proportion of them, as occasion demands, as commissioned officers.

Discussion took place concerning a proposed organization of American engineers urgently requested by French officials for services at the Front. The Executive Officer of the Council was requested to confer with the Chief Engineer, U. S. A., and offer the services of the Council in this connection.

Mr. Yerkes, Chairman of the psychology Committee submitted a report relative to the current development of the work of this Committee in connection with military needs.

After explanation by the Executive Officer the name of the Committee on Noxious Gases was changed to read "Committee on Gases used in Warfare." He also reported that upon order of the Surgeon General, U. S. A., Major Williamson, a member of this Committee, has been detailed for other duty and that Major Bradley Dewey of the U. S. Sanitary Corps has been appointed in his place as a member of the Committee on Gases used in Warfare. The Chairman of this Committee was furthermore authorized to appoint a representative of the Engineer Corps of the Army and to select a successor to Dr. Gatewood as additional members of the Committee.

Upon motion of the Chairman of the Chemistry Committee the following were appointed as members of the

Sub-Committee on the Chemistry of Fertilizers: F. G. COTTRELL, Bureau of Mines, Washington, D. C.; HOYT GALE, U. S. Geological Survey, Washington, D. C.; BAILEY E. BROWN, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.; JACOB G. LIPMAN, New Jersey Experiment Station, New Brunswick, New Jersey.

CARY T. HUTCHINSON, *Secretary.*